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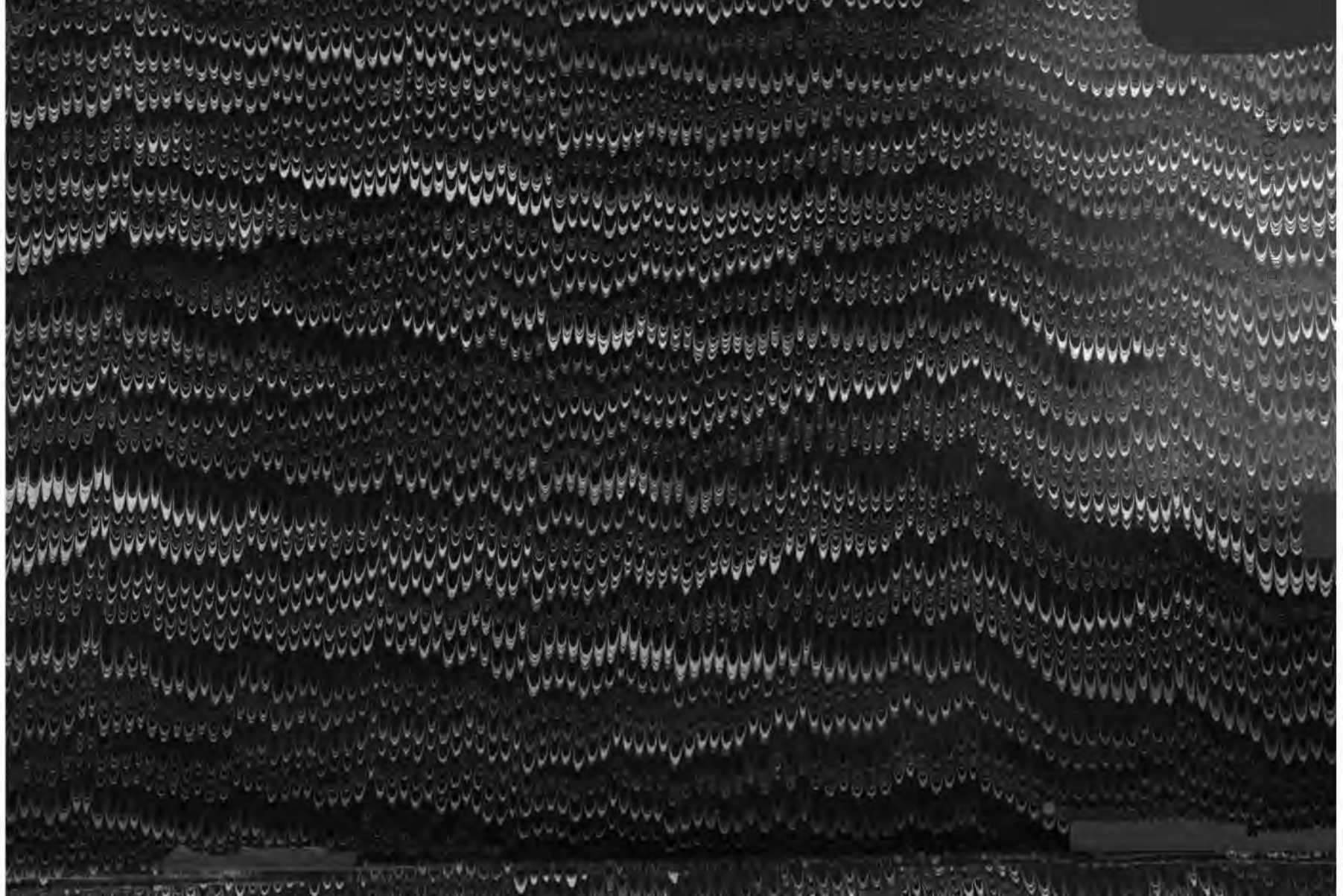

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IMPROVEMENT OF RIVERS AND HARBORS ON THE ATLANTIC COAST OF THE SOUTHERN STATES.

Abstracts of Reports of General Q. A. GILLMORE.*

I.

The character and magnitude of the works in progress along our Southern Atlantic border attract attention only when the brief summary of the year's work is published, and then excite a momentary interest, only, in the many who do not know that an engineering problem of great importance is in process of solution.

To aid, by artificial construction, in the establishment of a way permanently open to navigation, and free from the danger of accumulations of silt or sand, is the end sought. This requires, first of all, an intimate knowledge of the character and habits of all currents in the neighborhood, so that by properly directing them, they may aid, or at least shall not obstruct the end in view.

There is a widespread popular notion that the method of such improvement by *jetties* was first successfully applied at the mouth of the Mississippi, whereas such means have been employed, with more or less success, for nearly a century. The improvements at the mouth of the Danube, at Currachee in India, and the harbor of Dublin, are of this kind, and, under the name of piers or sea-walls, they are found in many important commercial ports.

The skill of the engineer is exercised when applying such a method, in adapting it to the special conditions which confront him in each case. A general plan of procedure, when a harbor is to be constructed at the mouth of a river, is to build piers or jetties out into the widened mouth of the river in such way as to continue the current of the stream, making the space between them as wide as the throat of the harbor or the waterway of the river; also to carry the jetties up to or above the surface of the water. One effect of this plan is to move the throat of the harbor to the outer extremity of the works, and to establish there the same conditions, so far as the deposit of a bar is concerned, as formerly existed nearer the mouth of the river.

In Charleston harbor, where the more important of the works covered by the report are in progress, Gen. Gillmore proposes to construct the jetties lower than usual, keeping them entirely below low water; also to make the width enclosed between them less than one-half the width of the natural throat of the harbor. The tide will therefore ebb and flow over the tops of the jetties. The

* Annual Report upon the Improvement of the Rivers and Harbors on the Coast of South Carolina, Georgia, and the Atlantic Coast of Florida, in charge of Q. A. Gillmore, Lieut.-Col. of Engineers, and Bvt. Maj.-General, U. S. A.

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object sought is to cut a narrow and deep channel through the bar without moving the bar.

"The bar which stretches bow-shaped across the entrance into Charleston Harbor, from Sullivan's Island on the north to Folly Island on the south side, has not varied much in either location, general direction, or magnitude within the period covered by any trustworthy knowledge which we possess on the subject.

"In the year 1852 a commission, composed of Prof. A. D. Bache, Superintendent of the United States Coast Survey; Lieutenants J. N. Maffitt, M. F. Maury, and C. H. Davis, United States Navy; and Lieut. J. D. Kurtz, United States Army, in a report on Charleston Harbor and Bar, made with special reference to works of permanent improvement, stated that a comparison of the chart of 1780, published in Des Barrés' Atlantic Neptune, with those of 1821, 1825, and 1851–'52, 'shows that according to the earliest records the bar of Charleston has varied comparatively but little in extent, direction, or in distance from the mouth of the harbor.'

"Measured along its crest, or line of least depths, the bar is ten miles in length, its north end on Sullivan's Island being close up to the entrance or throat of the harbor, while its south end, resting on Folly Island, is six miles distant therefrom. Its average width between the 18 foot curves is about $1\frac{3}{4}$ miles.

"In many places the highest points of the bar are only 3 to 4 feet below the level of mean low-water, although the average depths along the crest are considerably greater.

"The main central body of the bar, lying near due north and south, is nearly straight for a length of over five miles, has its crest parallel to the main shore south of the entrance and at a mean distance of about two miles from it, and is not at the present time, and, so far as we know, never has been traversed by practicable ship channels.

"The northern and southern extremities of the bar are formed by rather sharp curves, which connect the straight portion already mentioned with the shore above and below the harbor.

"So far as we can now ascertain there appear never to have been less than four nor more than six ship channels across the bar at any one time. The greatest depth of water has sometimes been found in one channel and sometimes in another, being rarely less than 12 feet or more than $13\frac{1}{2}$ feet at mean low tide.

"The channels, whether four or more, have always existed in two groups or clusters, one in the northern and the other in the southern curved portion of the bar, and there has always been a deep and broad anchorage inside the straight reach of the bar abreast of Morris Island.

"This anchorage, sometimes called the 'main channel' and sometimes the 'outer harbor,' varies in width from one-third to two-thirds of a mile between the 18 foot curves, and in maximum low-water depths from 20 to 45 feet. The direction of its central line is about north and south, and its length from the throat of the harbor between Morris and Sullivan's Islands to its southern terminus, where it spreads out in various channels and shoals in crossing the bar, is fully five miles. At the extremities of this outer harbor or basin, several miles apart, are found the two groups of channels already mentioned, the most northerly group being directly in front of the gorge of the harbor.

"The bar is essentially a drift-and-wave bar, produced in part by the upheaving action of the waves when they approach the shore, and are converted by breaking into waves of translation, and in part by drift material carried along the coast by surf currents, especially by those produced by northeast storms. The peculiar location of the bar, largely to the southward of the gorge of the harbor, and the conditions under which a very large proportion of the ebb-flow is diverted from its most direct path, and forced to skirt the main coast for several miles before it can find a passage to the sea, indicate the controlling power of these storms.

"The material composing the surface of the bar closely resembles that usually found on the sea shore between high and low water in that section of the country, being shells and fragments of shells, or silicious sand, or a mixture of them all. It is easily thrown into suspension by waves, and is moved by a moderate current.

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"On the north end of the bar five borings were made in order to determine the character of the substrata.

"All the channels which traverse the bar are, and, so far as we know, always have been, ebb-tide channels, produced and maintained by the scour of the ebb-current, except Beach (formerly Maffitt's) Channel, the most northerly of them all, which lies close to Sullivan's Island. This is a flood-tide channel, possessing the usual characteristic of such channels, that their least depths are always found near their inner ends, and, therefore, in comparatively quiet water. Another distinguishing feature of such channels is that from the cross section of shoalest soundings inward, toward the harbor, the descent into deep water is sharp and sudden, while outward, toward the ocean, it is gradual and gentle."

. . . . . .

"It having been determined to begin the works by laying so much of the apron foundation of the North or Sullivan's Island jetty as the appropriation made June, 1878, would cover, a careful survey for location was made of a strip or belt of the bar about 800 yards wide and 5,000 yards long, extending from Sullivan's Island in a southeasterly direction, so located as to embrace the whole of the north jetty, even should it be deemed expedient, in view of the additional information recently obtained, to add largely to its length, and make very considerable changes in its location.

. . . . . .

"The following extract from the specifications which formed part of the contract under which the work of 1878 was executed, describes in general terms the apron of the north jetty, according to the original plan:

"'A design for the apron has been prepared in this office, which is deemed suitable for the purpose. It consists essentially of a platform of round logs from 11 to 12 inches in diameter, placed and held close together, side by side, at right angles to the axis of the jetty. The logs are to be as straight as can be procured, and those of about the same size must be selected to go together. This log platform is to be overlaid by a compact layer of stout brush to a depth of 12 to 14 inches, projecting from 10 to 12 feet beyond the ends of the logs on either side, the projecting portion being closely confined and bound together so as to form a kind of mattress. As much brush should be used as the logs will bear up and float. Upon this wooden substructure, which will be at least 2 feet thick, good soundstone of random sizes and of compact form, but none weighing less than 30 pounds, will be placed as compactly as possible. The depth of this bed of riprap stone will be $2\frac{1}{2}$ feet for all that portion of the work that constituted a part of the stone superstructure and lies within the side slopes of the jetty, while a depth of only 1 to $1\frac{1}{2}$ feet will be required upon that portion on either side which projects as a mattress beyond the foot of the side slopes.

"'The total length of the north jetty, according to the original plan, is about 8,840 feet. This may be increased hereafter.

"'The width of the log platform at any point will be regarded as the bottom width of the jetty at that point. As the apron progresses the pre-arranged widths may require a slight increase in consequence of scour in advance of the work. The greatest bottom width of platform will be about 92 feet, and the least will not be less than 33 feet. The average bottom width may be a little greater or less than 52 feet, but for the purpose of bidders will be taken at 52 feet.'

"In November the contractors requested a modification of the specifications, with respect to the method of making the mattresses, constituting the bottom portion of the apron. They proposed to make the log platform 10 feet wider than the contract required, to omit the joints in the logs, and restrict the projection of the brush beyond the ends of the logs to 4 feet.

"In forwarding this proposition for the action of the Chief of Engineers, it was stipulated, with the contractors' written consent, that the projecting brush was to be close and massive, although not formed into a mattress as in the original plan, that the quantity of riprap stone used in the apron was to be the same as specified in the contract, and that the cost of the work to the United States was not to be increased; also, that none of the riprap stone was to be placed upon the projecting brush, all of it being

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distributed above and over the area occupied by the log platform.

"These proposed changes in the details of the plan were approved by the Chief of Engineers, under date November 13, 1878.

"A cross-section of the apron, according to the design as amended, is shown in Fig. 2.

"The comparatively low bottom velocities of the ebb current observed on the seaward slope of the bar seemed to point to the necessity of giving the jetties greater length than that contemplated in the original project. It was thought best also to adopt a longer radius for the curved portions of the north jetty, and to carry the point of tangency between it and the straight portion farther to seaward.

"It was determined to retain the original point of departure from the line of ordinary high water on Sullivan's Island, and to carry out the jetty for a length of 8,840 feet, on an arc of a circle described with a radius of 2½ miles, so located that a straight tangent at the sea-end of the arc would have a direction about east 32 degrees south.

. . . . . .

"The contractors, anticipating great difficulty in laying their work upon a shoal lying in the line of the north jetty, known as Drunken Dick Shoal, which is covered with breakers a great portion of the time, requested, under date April 21, 1879, such a change in the location of the line of the jetty as would in effect divert it to the westward, thereby escaping a portion of the shoalest water, and diminishing the quantity of work to be put down in the breakers.

"The work from the beginning had been laid upon straight ranges, or chords of 400 feet in length, and not upon the circular arc of 2½ miles radius. By the change desired the line of the work, after completing the eighth chord, 3,200 feet from ordinary high-water mark on the shore, would continue on the straight prolongation of that chord for a distance of about 3,000 feet, or until Drunken Dick Shoal was crossed. This change of direction was approved for a length of 2,000 feet beyond the eighth chord, leaving it to be determined, when that limit shall have been reached, whether the work shall be continued on the straight line, or on an arc of 2½ miles radius parallel to the original arc, or otherwise.

. . . . . .

"The width of the log platform which forms the base of the structure varies from 43 feet to 66 feet. These widths include the 10 feet added in modifying the design as already noted, and, therefore, exceed by that much the widths on which payments have been made.

"The riprap stone is required by the contract to be sound stone of random sizes, but none weighing less than 30 pounds. The maximum sizes were not specified, either by weight or dimensions, and the contractors assumed and insisted on the right to exclude heavy stones. The largest pieces are such as one man can pick up and throw overboard from the scows used in conveying the stone to the jetty, while the smaller sizes run somewhat under the prescribed limit of 30 pounds. As these latter, however, in great measure go to fill up the interstices between the large pieces, thus increasing the weight of the mass without materially adding to its bulk or cost, no objection has been made to their use to a moderate extent.

"The frequent inspections that have been made do not show that any of the stone has yet been carried off the apron by the force of the waves, and perhaps no apprehension need be entertained of serious disturbance from this cause to any of the work already laid, unless it be on that portion put down in June, 1879, on the inner slope of Drunken Dick Shoal, where the depth at mean low-tide does not exceed 8 to 8½ feet. It seems hardly safe to assume, however, that stone of such small sizes will continuously withstand the force of the waves on the crest and exterior slope of the bar. Not that there is likely to be any sudden movement of large masses, but that the waves produced by the prevailing heavy storms, those from the northeast, will carry the stones gradually, a few only, and for short distances at any one time, from the inner slope of the jetty to its crest, and thence over to the western slope. Large stones will have to be used for the upper portions of the work, and some device may have to be resorted to for holding them in place.

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"The design of the apron is such that the log platform which forms its base would be exposed to the ravages of the teredo unless covered with sand or other material placed upon the ends of the logs, or accumulated there by the action of the currents, or by the settlement of the structure.

"An examination made on the 24th of June shows that for a length of about 1,450 feet from the high-water mark on Sullivan's Island, comprising all the work laid before the 4th of February, the apron is so well embedded in the sand as to afford a complete protection to the wood.

"Most of the work laid in February, and all laid subsequent thereto, is more or less exposed, and directions were given near the end of June to cover the exposed wood with riprap stone.

"No settlement of the work has been detected on any part of the line."

As set forth in a former report, the plan is stated in these words:—

"It is proposed to construct two jetties, one springing from Morris Island and the other from Sullivan's Island, converging toward each other in such manner that their outer ends on the crest of the bar *shall be one-half to five-eighths of a mile apart.* The outer ends of the two jetties will rest respectively upon the shoals lying to the northward and southward of what is known as the north channel, that being the middle channel of the north group of three channels, and having its line of deepest water located, more nearly than either of the others, upon the prolongation of the axis of deep-water flow through the gorge of the harbor between Cumming's Point and Fort Moultrie.

"Assuming, for the purposes of discussion, the sea ends of the jetties to rest respectively at X and Y, it seems, in some measure, immaterial whether they be established upon straight lines, as shown at AX and BY, or upon curved lines; and if curved, whether the convexity be turned toward the central channel, as at CX and DY, or from it, as at EX and FY. In either case, if kept at the proper heights, they will produce an ebb-flow through the gap able to maintain a deep channel through the bar. Neither the straight jetties, however, nor, more especially, those with their convexity turned away from the channel, act as training-walls to guide the outflowing water. The curved jetties, convex toward each other, being less open to this objection, are the ones adopted in this project.

"The north jetty starts from a point on Sullivan's Island, 1,800 yards east of Bowman's jetty. The half next the shore is curved to a radius of about 1½ miles, the outer half being very nearly a straight line. The total length of this jetty, from C to X, is 7,450 feet, and its general direction is southeast.

"The south jetty, having a total length of 11,650 feet, from D to Y, starts from Morris Island at a point about 650 yards from Cumming's Point, its general direction being east. The shore end is curved to a radius of about 3 miles for a little more than one-half its entire length, while the half next the sea is nearly straight, as in the case of the north jetty.

"The specified length of the jetties is taken for purposes of discussion. As will be seen hereafter, they would not be able to produce a channel of the requisite capacity through certain materials which may be encountered in the bar, although they would be expected to maintain such a channel if once established.

"The outer ends of the two jetties slightly converge toward each other as they approach the crest of the bar, and are intended to act as training-walls for a distance, in each case, quite equal to half its entire length. These portions lie in the direction of the flood-currents, and may be built to any height without obstructing the inflow. For fully one-fourth of their entire length the sea ends could be carried above the level of high-water, so as to be visible at all stages of the tide. The inner portions, crossing the Beach and main channels, respectively, might perhaps be kept low enough to allow the smaller classes of vessels to pass over them.

"One characteristic feature of the design—that of low jetties—is intended to maintain the bar in its present general location, with such moderate increase of magnitude as may be expected to result from concentrating, upon a gap one-half to five-eighths of a mile in width, a portion of the water which is now dispersed over a width of 10 miles.

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"The complete success of the works is believed to depend on three important conditions, which they are expected in a great measure to satisfy, and which have been kept in view in preparing the design, viz.:

"1. *They should not impede the influx to such degree as to prevent the tidal basin being filled, as now, at every influx of the tidal wave.*

"To this end the inner half of each jetty, more especially its central portion, located in deep water across the thread of the current, is kept several feet below the water. The outer half, being nearly parallel to the direction of the flow, is built higher, and the sea end, for a distance of several hundred feet, may be carried high enough to be visible at all stages of the tide.

"2. *They should control the outflow to such degree, and in such manner, that a channel of the required depth will be maintained through the bar.*

"To this end, although a large portion of the *surface flow* will spread out over the tops of the jetties and thence over the bar, the *central flow*, throughout the entire depth along the axial line of the gorge between Sullivan's and Morris Islands, is aided in its natural tendency to reach the sea along the prolongation of that line by the opening left for it between the jetties. The *bottom flow* through the gorge of the harbor is deflected on converging lines by the jetties, and is, therefore, forced in a measure to concentrate itself in, and flow out through, the gap between them. The outer half of each jetty, and the adjacent portion of the shore end act as a training-wall for this flow.

"3. *They should not, to any considerable extent, cause a movement seaward of the main body of the bar; that is, the general position of the bar should be independent of the effects produced between and beyond the heads of the jetties.*

"It is believed that this condition will be secured by making the shore ends of the jetties low for at least one-half their length, or throughout those portions which cross the thread of the current in deep water, so as to allow the tide to ebb and flow somewhat freely over them. The effect of high jetties, with a correspondingly wide gap between them to allow a full influx of the tide, would tend to transfer the gorge of the harbor from its present position to the sea ends of the jetties and move the shore line out to that point, by causing a filling in of the exterior angles between the jetties and the shore. After reaching this stage, a drift-and-wave bar would probably be found to the seaward of the present bar, in front of the jetties, rendering it necessary to extend them, in order to cut a passage through it.

"It seems essential, therefore, that the agencies which maintain the present bar should remain in as full force as possible, consistent with the requisite concentration of outflow between the jetties.

"The probable effects will be that the bar will be raised somewhat throughout its entire length, the waves will break upon it more frequently than now, and considerable shoaling will, of course, take place in Beach Channel and in all the southern group of channels. But it is believed that the important condition of keeping the bar generally in its present position will be secured.

"The drift material carried along the coast by surf-currents, as well as the sand thrown up by the breakers on the north and south shoals, instead of lodging in and filling up the exterior angles between the jetties and the shore, as in the case of high jetties, will be disposed of in a harmless manner.

"For example, a heavy northeasterly storm, producing breakers along the north shoal and strong southerly surf-currents along the shores of Long and Sullivan's Islands, would put in motion a large quantity of material, a portion of which would be carried in by the flood-currents over the north jetty and through Beach Channel, coming to rest in the deep water of the main channel. It would next be taken up by the ebb-current and rolled out to sea between the jetties. Beyond the jetty-heads it would encounter the littoral ebb-current, moving to the southward with a velocity accelerated by the storm, by which it would be again carried in a southwesterly direction, until, finally, left to the action of the south breakers, it would be either deposited temporarily upon the south shoal, or carried still farther to the southward.

"The action of a southerly storm would be the reverse of this. In either

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ase some drift-material would be carried by waves and surf-currents around the jetty heads, and would subside in the deep water between them, to be swept out by ensuing ebb-currents, and disposed of to the northward or southward, according to the direction of the storm.

"This movement of sand was referred to in my report on the improvement of the Fernandina Bar, submitted April 15, 1876, from which the following extract is made:

"'As a moderate assumption, a northeaster of three days' duration might be expected to lower the north shoal four inches within the area covered by the breakers. The greater part of the eroded material, amounting to upward of 516,000 cubic yards, would doubtless be distributed along the south shoal during the progress of the storm. If the waves should subside, or a southerly or southeasterly storm set in before the bar channel had returned to its normal condition, the material subsequently carried out would not reach the south shoal, but in the former case would remain near the outlet on the outer slope of the bar, and in the latter would be carried back by the waves to the north shoal. If as much as one-fourth of it remained in the bar channel, between the inner and outer 18-foot curves, a few severe storms, such as frequently occur within the period of a single month, would entirely destroy it, by filling it up to the level of the shoal on either side.

"'It would appear, therefore, that millions of cubic yards of the material composing the bar might be shifted back and forth from one side of the channel outlet to the other, during a single season, without causing injury to the channel by shoaling, and without producing any changes in the form and location of the bar itself that might not entirely escape the notice of the most careful surveyor. And yet this shifting of material, of which no evidence may be left behind, should enter as an important, if not a controlling, function in the project of the engineer, because the useful life of his works is more or less dependent thereon.'

"As no works can be expected to stop this movement of drift-material for any great length of time, they should, if practicable, accommodate themselves to it under conditions of a permanent character. Those proposed are designed to do this, by allowing the drift-sand to move from one part of the bar to the other, in much the same manner as now, never remaining in the jetty channel longer than a few tides, and never finding a resting-place anywhere that the next storm may not disturb."

From the forthcoming report we learn that:

"During the fiscal year just closed, the work of putting down the apron of the North jetty was continued, and the construction of the South jetty was begun.

"The foundation matters of the North jetty continued to be made after the modified design (see Fig. 2). Another modification in this contract was made August 19, 1879, under which a mattress was inserted as a hearting in the rip-rap superstructure of the apron, in order to get increased height by the use of a material less costly than stone.

Fig. 2.

"This second mattress, which is in all essential features like the lower one, has a prescribed thickness of 18 inches in the finished jetty, and is paid for in the work at the rate of $5 per lineal foot of mat, fifty-four feet wide, equivalent to $1.66⅔ per cubic yard. When the bottom mattress has been sunk and loaded with stone to the depth of a few inches, as evenly distributed as possible, the second mattress is sunk in its place, and the balance of the 2½ feet layer of stone, required by contract on the apron, is placed upon it.

"The width of the second mattress is uniformly less, by 32 feet, than of the one at the bottom, in order that the rip-rap superstructure laid with flat slopes will cover it and protect the ends of the

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logs from the ravages of the teredo. Less apprehension of injury from this cause is felt for the bottom mattress, for the reason that from its position, directly on the bottom, it is likely to become quickly covered with sand whenever there is any tendency to fill at all.

"When the apron of the North jetty had attained a length of about 5430 feet from the shore, in only 5 feet low water soundings on the inner slopes of Drunken Dick Shoal, work was suspended on account of rough water and breakers, and resumed on the seaward slope of the shoal, at a point on the amended curve of location, leaving a gap of 1647 feet to be filled in hereafter.

"If this shoal, which at present shows, on some portions of it at least, indications of considerable stability, shall continue to resist abrasion and wear, after the work on each side of it reaches the required height, there will be no special need of re-enforcing it, or of raising its surface artificially. If, on the other hand, it yields under increased currents, or wherever it does yield and wear away from any cause, increased depths will be the result, and the breakers will doubtless subside to such a degree that there will be no special difficulty in laying the work.

"During a spring tide of considerable range in the month of July, 1879, a large portion of the shoal was laid bare at low water, and part of a wreck which has doubtless been there for some years was discovered on it, indicating that the material of the shoal has considerable firmness and tenacity.

"So far as known, this precise locality has never been examined by boring.

"When work under the first contract was finished on the outer end of the jetty, the use of the second mattress, which is not adapted to the thin courses of the later contract, was also discontinued.

"The prosecution of work upon the North jetty since the 10th of May, and upon the South jetty since the 23rd of April, has been in conformity to a contract dated September 6, 1879.

"Under this new contract the engineer-in-charge has the power to regulate the height of the jetty by laying it in one or more courses, and the work can be prosecuted by extending the North jetty, and raising it higher at certain points, and by beginning the construction of the South jetty.

"Among the specifications of the contract for the work to be done this year is one for mooring chains of wrought iron, to be afterwards used in securing the top layers of stone on the finished jetty, against removal by the waves, will be attached to the logs of certain mattresses at intervals of 40 to 50 feet along the line of the jetty where most exposed to the force of the waves. The lower end of each chain terminating in a ring will be supported by a buoy, spar, tripod or otherwise, so that it will not become covered up with stone, and can be found at any time. The chains will be galvanized in the best manner.

"These galvanized mooring chains will be what is known as chain cables, and will be of such sizes, not less than 1 inch, nor more than 1¼ inches in diameter, and of such lengths, and attached to such mattresses, and at such distances from the sides thereof as the engineer-in-charge shall direct.

"A second course will probably be placed on some portions of both jetties before, or during the coming Autumn.

"It is not the present intention to give the base of the south jetty, during this fiscal year, its full width where it crosses the main ship channel in about 40 feet low water soundings. It seems desirable that as great height as possible should be gained in this deep water with the funds now available, and the work will therefore be laid in two or more courses, the bottom one being about half the required width. It is possible that the sand will fill in so rapidly that the full width of base adapted to this great depth will not be needed. When the bottom course, rising to a height of about 2 feet 8 or 9 inches has ceased to accumulate sand, the second course will be laid, and after that perhaps a third course in some places.

"An inspection was made a few days before the close of the fiscal year, of the entire line of work on the north jetty. No settlement was detected in any portion of it, except in the deep water of Beach Channel, where for a length of 200 feet a subsidence seems to have taken place varying from 1 to 3½ feet, the immediate cause of which has not been ascertained.

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"On that portion between Drunken Dick Shoal and Sullivan's Island, the ends of the logs are reported to be well covered with sand, except when the low water depth does not exceed 8 feet. On former examinations the timber even in this shoal water was found to be covered. The cause to which its present exposure is to be attributed, cannot be positively stated.

"South of Drunken Dick Shoal the ends of most of the logs remain uncovered, and exposed to the ravages of the teredo.

"It is proposed to cover all the exposed timbers with rip-rap stone, and steps have been taken to procure it as soon as practicable.

"It is found that sand accumulates very slowly around the ends of the logs, on the south jetty. No settlement is reported there.

"A few months before the close of the fiscal year, I had an opportunity to examine the shore end of the north jetty, at an unusually low stage of water, and I found that the rip-rap stone, placed there 15 months before, had become so firmly cemented together with barnacles and other shell-fish accretions, as to render the mass remarkably dense and compact.

"It seems quite improbable that the stone, even on the most exposed part of the work beyond the bar, will ever be washed off or moved by the waves, if it can once be consolidated in this manner by the molluscan growth of a single summer.

"It may be hoped, therefore, that recourse to the mooring chains, for holding a line of large stones, linked together along the crest of the work, for which provision was made in the contract, will not be necessary.

"The work has not yet reached that stage when increased depths can be expected in the swash channel, which, occupying the proposed gap between the two jetties, is, nominally, the one to be improved.

"But it is neither expected nor desired that the improved channel will occupy the line of the present one. It is a crooked channel lying at an average distance of not less than 1,400 feet from the line selected for the North jetty. On the shoals lying between it and that jetty, however, a marked increase of depth, amounting to three feet, over considerable areas, has taken place during the past year, which is to be attributed to the direct action of the jetty. The changes were more rapid as the jetty advanced. The effect has been to move the inner end of the swash channel northward. It may be expedient to assist, by dredging, this developed tendency to scour along the line of the proposed channel, when the time for such auxiliary work shall have arrived.

"During the month of June, 1879, arrangements were made to cover the exposed logs, north of Drunken Dick shoal, with ballast stone and brick-bats; but the sand eventually collected along the margin of the work sufficiently to afford the requisite protection. Only 18 cubic yards of brick and stone were placed on the work under this agreement.

"During the present fiscal year, it is expected that both jetties will be extended, and, in some places, raised to a higher level under the existing contract, and others to be entered into hereafter, by methods the same, or substantially the same, as those hitherto followed; and, if deemed advantageous, some dredging will be done by the United States dredge steamer 'Henry Burden,' along the line of the proposed channel.'

Coal in India.—Theodore W. H. Hughes begins a paper on the coal fields of India by saying: "It will doubtless surprise many to learn that both in the superficial extent of its coal measures and associated rocks, and in the actual amount of its coal, India is surpassed by few countries, and that with respect to the size of some of the seams it stands pre-eminent in the history of mining." Even the United States cannot boast of seams 100 feet, 120 feet and 160 feet thick, like some that occur in Bengal. He calculates that the coal fields of India cover 35,000 square miles, and according to estimates drawn up by Dr. Oldman there cannot be less than 20,000,000,000 tons of coal in the Empire. Much of the material, however, is of an inferior quality and fit only for very rough use. —*L'Ingen. Univ.*

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THE VALUE OF THE STUDY OF THE MECHANICAL THEORY OF HEAT.

By ALFRED R. WOLFF, M. E.

A Paper read before the American Society of Mechanical Engineers, November 5th, 1880.

I

In presenting a few remarks on the Value of the Study of the Mechanical Theory of Heat, I am imbued with the knowledge of two facts: of the importance and value of the study on the one hand, and of, in general, a lack of proper appreciation among engineers of this point on the other. There are doubtless few among educated engineers who would not admit that the acquisition of any form of knowledge is of value, not only as a training of the mind but as an addition to our understanding of the laws and working of the universe and mankind; few who would deny that the study of literature, of social or politico-economic sciences would be of benefit to them, though of limited influence in the practice of their profession.

From personal experience, as well as from the experience of others, I am led to believe that engineers, as a class, look upon the knowledge of the mechanical theory of heat not much unlike than that of the department of "belles-lettres," as possibly adding to refinement, to a broader view of things in general, to a fair drilling of the mind, but of no practical or only slight practical value in the ordinary, or even extraordinary, exercise of their profession. I am not prepared to say that were the grounds above enumerated the only ones upon which the study could be urged, that a strong argument in favor of its more general introduction could not justly be maintained; but this question does not arise since the more general introduction of the science can be presented to the engineer on the ground of direct, practical utility, for the purposes of correctly appreciating and increasing the efficiency of a large department of his profession, that department which treats of the transformation of the latent or active forces or powers of nature in a form suitable for application as motive power for utilization in machinery designed to do the desired special work, or, in other words, to that department which relates to the generation of the working fluid or motive power, and the work performed by the medium of such fluids in prime movers. It is on this ground that I would urge the more general acquisition of the science of thermo-dynamics, and to insure conciseness as well as a ready conception of my views, I will only briefly outline the thoughts, giving as it were their direction, and leave it to you to give them force, that is, to develop them more fully as your own understanding and experience will best suggest.

Thermo-dynamics or the Mechanical Theory of Heat is, as the name implies, the science of the laws of heat considered as a form of energy. It is based upon two great, general laws, the one that all forms of energy are mutually convertible in certain exact, invariable equivalents, the other that the quantity of energy in a homogeneous substance is equal to the sum of the energy of its component parts, and that equal parts of a homogeneous substance when undergoing a change of, or exerting, energy undergo like changes, and exert like effects. The application of these two fundamental laws of energetics to heat constitute the determination of the two general laws of thermo-dynamics, which are the basis of the whole science, and of which the science is in fact but an extension and application to forms of heat energy, latent or active, met with in nature and valuable in practice. For after all what is theory but practice reduced to a connected system of laws or principles. Without facts, without phenomena, in short, without practice as a foundation, how could theory ever be conceived or established? In ordinary discussion but little attention is paid to the distinction between theory and hypothesis, and nothing has proved more dis-

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astrous to a general appreciation of theory than the repeated misuse of the term. Theory is based on facts, hypothesis on speculation, hypothesis changes to theory when speculation changes to facts. The two special laws of thermo-dynamics, upon which the whole science is elaborated, to which we refer are: that heat is convertible to other forms of energy in the relation of what is known as Joule's equivalent, that is, that one thermal unit (the quantity of heat required to raise one pound of water at 39.4° Fahr., one degree in temperature) is equal to the energy required to raise 772 lbs. 1 foot, or that 772 lbs. falling 1 foot will develop sufficient heat to raise 1 lb. of water at its greatest density 1 degree. The second is that if the total actual heat of a homogeneous and uniformly hot body undergo a change or exert energy, equal parts of the body will undergo equal changes and exert like effects, the sum of the effects of the component parts being equal to the total effect. This law is more popularly identified in the form of Carnot's theorem, a special application to heat engines, that $q-q_1$ or $\frac{T-T_1}{T}$, is the limit of efficiency of such engines, and that the test of a perfect engine is its reversibility. q and T represent respectively the quantity of heat and absolute temperature of the (any) fluid when leaving the generator, and q_1 and T_1, respectively, the quantity of heat and absolute temperature of the fluid when given off to the refrigerator; $q-q_1$ when entirely converted into useful work causing the engine to become theoretically perfect.

The above outlines the foundation and framework of a great science. It is strong and simple, and in its strength and simplicity beautiful. The structure and superstructure are equally strong, equally beautiful, but not, however, equally simple. If this were the case there would be little need of the presentation of papers of this kind, for the great value of the science would be universally acknowledged. It is a common experience that the mass of mankind primarily pronounce that which is difficult to attain as not worthy of attainment, primarily too often look upon those who have mastered the difficult with scornful or doubting eye, until the achievement of the difficulty by the few has brought forward such valuable results, such striking truths, so influences the ordinary experiences and our conception of facts in nature or in our professions, that the worthiness and value of the attainment can no longer be denied and must be definitely accepted. That point has now undeniably been reached in thermo-dynamics, and the sooner we concede it the better. The sooner we admit that we must study and explore the science of heat energy in its higher form, the sooner will we advance in our profession and contribute to its progress. It will be my aim to recall a few of the practical applications in engineering of the principles which thermo-dynamics has established, and thus to give an illustration or rather indication of its value. But before doing so to be strictly conscientious, I must refer to the difficulties to be met with in the study in its higher form. Professor McCulloch says: "Any one acquainted with only the elements of analytical geometry, and of the fluxional calculus, should find no difficulty in understanding all it contains. In this country, however, scientific education, as well as classical, has unfortunately retrograded; and superficiality is the fashion of the day. Hence, some anxious for scientific knowledge, with the least labor and in the shortest time, imagine it might be well in scientific literature to dispense with the calculus. To them no better advice can be given than to begin by studying it thoroughly, if they would reasonably hope ever to comprehend much which would otherwise be unintelligible."

These elements, however, must be firmly fixed in the mind, and thermo-dynamics may justly be considered a thorough test of such a knowledge. When beginning the study of the subject, I thought I had fairly mastered calculus, while engaged in its acquisition I found I was a mere novice, and such too has been the experience of a few of my friends who have already progressed and done good work in the science. But let us not be deterred from the acquisition of a valuable subject because of its difficulty. This

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really incites a person to a hard effort, and the gratification which the mastering of an important point gives, forms an incentive to further advance which acts more potently than the repulsive part of the difficulty. Let us not accept the valuable principles reached without making at least an honest effort to follow the masters who have discovered them, and thus make the principles in reality our own. But if our comprehension and efforts will not permit us to do this, let us not cry down the methods by which they were attained, and let us study the principles themselves thoroughly.

There is a wonderful harmony in nature—without it all scientific research would be of no avail. There are certain great invariable laws, some determined and many more not yet conceived, but in our faith in and knowledge of the reliability of those laws exists the only safeguard of advance. This opens up that large realm of reasoning known as "by analogy," and enables us to determine thus, and by analysis, laws which are not directly determinable from our practical experiences or observed phenomena. Heat, the observed and usually acknowledged primary physical source of all energy (though gravitation might on some good grounds be selected as our present ultimatum) beautifully illustrates this harmony when considered as energy, and thus prescribes laws which are afterwards varified in practice, and to which practice conforms and becomes the embodiment of. This is the strongest plea which it seems to me can be urged for the careful study of the mechanical theory of heat, and we will attempt to point out some of the work which has been done in this respect, and leave it to your judgment to decide whether a science which has already accomplished so much is not capable, when many able minds are devoted to its study, of an application and extension which is and will be of incomprehensible value in the ordinary practice of the engineer, and which will greatly contribute to the advance of mechanical engineering.

The specific heat at constant pressure of any permanent gas can be ascertained directly by experiment, not so the specific heat at constant volume. Regnault has made accurate determinations of the specific heat of such gases at constant pressure, and discovered certain laws relative to the same, that the specific heat of such a gas is independent of its temperature and density, and the product of the density and the specific heat is the same constant for all permanent gases. From the velocity of sound, independent of the principles of thermodynamics, the specific heat at constant volume for a permanent gas can be determined, and these two quantities when substituted in an equation of the theoretical value of the mechanical equivalent of heat, expressed as a function of the pressure, volume, dilatability, and the two specific heats of a permanent gas give for this equivalent a theoretical value which agrees with that practically determined by Joule, and recently verified by Professor Rowland. I need not dwell upon the mathematical exposition of this, but reference to Stewart ("Elementary Treatise on Heat," pages 330 & 412), Maxwell ("Theory of Heat," pages 169, 228, & 310), Cotterill ("The Steam Engine Considered as a Heat Machine," page 82) McCulloch ("Mechanical Theory of Heat," page 92) and Rankine ("Steam Engine," page 321) will serve as a verification of the above summation. Permit me to call your attention to this remarkable agreement between theory and practice. The specific heat at constant volume is not directly determinable from experiment, so it is developed from the velocity of sound, and substituting these two independent experimental data (the two specific heats) in a theoretical equation not involving a previous determination of the mechanical equivalent of heat, we ascertain such equivalent from correct theoretical considerations, and it accords with the experimental determination. What a beautiful demonstration of the correlation of the different laws and facts of nature do we here perceive exemplified.

But this will appear rather as an illustration of the beauty and symmetry of the science than as a presentation of a fact of direct utility to the engineer in the practice of his profession, and since it is my special object to call attention to a few of the latter class of facts, I will have to omit the mention of the interesting relations between the physical properties of bodies, such as between the two elasticities and the two specific heats,

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gaseous viscosity and the molecular theory of the constitution of bodies, all of which the science teaches and will at once refer to its main application for our own purposes, the work of fluids in engines. It is in this department of our profession that thermo-dynamics has made the deepest impression in practice, and is destined to continue it to a far greater extent. It has taught us the different laws of expansion and work of fluids, and has supplied us with the proper test of the efficiency of different forms of engines. $\frac{T-T_1}{T}$, the limit of efficiency has enabled us to correctly appreciate the progress made, and to definitely point out the direction in which the advance in efficiency and perfection of heat engines lies. To increase the theoretical efficiency, T, the temperature of the fluid at its entrance to the cylinder should be raised, and T_1, the temperature at exhaust lowered as much as possible.

The application of this principle to steam engines implies high steam pressures and great expansion. This was tried within certain limits, and the beneficial results looked for were not realized to the extent expected. The theory was still recognized as true by those who grasped it, but the practical results had not conformed to their expectations. The nature, laws and action of steam were thoroughly investigated, and it became apparent that condensation ensued, owing to heat consumed for internal work during expansion and to the detrimental action of the metal of the cylinder. When the steam enters the cylinder (of a lower temperature than the steam at its initial pressure) it gives out heat to the metal of the cylinder, and to do this sets free latent heat, causing water of condensation to be formed. When the steam in the cylinder expands it performs internal as well as external work, and becomes partially liquefied; as the steam leaves the cylinder, rushing into the condenser, the water mixed with the steam evaporates, abstracting additional heat from the metal of the cylinder. When a fresh volume of steam of initial pressure now enters the cylinder, it comes in contact with the metal of lower temperature, water of condensation is formed and the action continues as indicated above.

Several methods of decreasing this loss presented themselves:

1. The introduction of the compound engine which dividing up the range of temperature between admission and final exhaust, in two or more stages, causes less difference in each cylinder, and therefore decreases the loss by condensation while again the heat abstracted from the first cylinder at exhaust becomes available in the second cylinder.

2. The use of the steam jacket which tends to keep the metal of the cylinder at uniform temperature and thus prevent the initial condensation of steam, and to supply heat to the steam in the cylinder to prevent condensation during expansion.

3. The introduction of a great number of strokes per minute so that less time will be accorded to the steam to impart heat to the metal of the cylinder and to abstract heat during exhaust.

4. The use of superheated steam, since it can emit heat when being admitted to a cylinder of lower temperature without causing water of condensation to form at entrance or during expansion.

Neither of the first three remedies proves entirely efficacious in practice while all have greatly reduced the loss from condensation. An intelligent study of the theory of heat will show, however, that the latter is the only one which offers the possibility of entirely preventing condensation. Perhaps it will need some explanation why the steam jacket can never entirely prevent this loss. It is owing to the fact that the transfer of heat from the steam in the jacket is not as rapid as the transfer of the heat from the internal sides of the cylinder to the steam in cylinder, that the steam on entering the cylinder heats up but a small thickness of metal to its own temperature, owing to the comparatively poor power of conduction of iron. And the steam in the jacket, similarly, heats up to its own temperature but a small thickness of the metal of the cylinder immediately in contact with it; in brief, the poor heat-conducting power of iron does not allow the transfer of heat from the steam in jacket to the steam in cylinder to be practically instantaneous.

There may be some who are opposed

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to the introduction of the high speed (as they are popularly termed) or rather "high revolution" engines. But whatever be their practical defects—and they possess some mechanical advantages that we are inclined to think more than counter-balance those defects—the principle is in the right direction, and al ready splendid workmanship and refinement of mechanism and machinery tends to confirm the value theory accords the system.

We will now briefly refer to the use of air. Thermo-dynamics demonstrates its superiority to steam. Its permanently gaseous nature enables it to expand without doing internal work, and its temperature can be raised to a high degree without the objection of a high pressure difficult to control. But practically the few air engines built have as yet not proved a decided success, owing to the difficulty of obtaining a rapid connection of heat to and from the air employed, and the necessity of a larger cylinder than is needed for a steam engine of the same power. Again, very high temperatures of the air cause no inconsiderable strains due to irregular expansion of the metal and a slow oxidation of the metal as well. And so with other forms of fluid engines. Practical difficulties and obstacles have not always permitted the rigid teachings of thermo-dynamics to be precisely realized, though they have in most cases served as an exemplification of its truth. But as long as we have the laws of the mechanical theory of heat to teach us where the possibility of or road to progress lies, better steam and better air and better gas and better fluid engines will in time be built. Even with the fluids and materials at present known, the performance of engines are capable of being doubled, a result by no means too trival to make an honest effort to master the principles which will aid us in securing this end. But who would dare to say in an age when Professor Crooke s fourth state of matter opens up realms of investigation undreamt of, and when Professor Bell's discovery of sound transmitting rays of light potently reminds us that we are but at the threshold of our understanding of the laws of the universe, who would dare to say that new fluids, materials and conditions will not be discovered that will enable us to extend the limits of temperature between which the fluid can expand in a cylinder, and thus utilize by far the greater portion of the latent power which nature has presented to us in her stores of fuel!

But it may be said: The advances, pointed out above, in the efficiency of engines have not in all cases been instituted by those who have mastered the mechanical theory of heat, and the advances, therefore, are not in all cases the result of the study of the subject. This is partially true, that is while, as far as I can learn, no advances have been secured in the efficiency of heat engines (not including, of course, reduction of friction and better mechanism for transforming the rectilinear motion of the piston) by men who have not been intimately acquainted with, at least, the fundamental principles of heat energy, they have not in all cases mastered the whole subject in its highest mathematical form. But to correctly appreciate and define the advance, the theory of heat energy has always been called into play, and if our progress in the efficiency of heat engines has not been as rapid as we might have desired, and is not as rapid at the present time as desirable, it is owing to a lack of knowledge and understanding of the subject under discussion by some of our more brilliant and experienced minds. There are two methods of gaining knowledge. One by acquiring the laws and results of the experience of others, the other by acquiring the laws by our own experience. Both constitute the acquisition of principles or theory. Both have their uses. But it is a loss of time and it is at the expense of many failures and disappointments which do not contribute to real advance, if we arrive at the same principles by such failures that others have reached before us by whose experience we might have profited. When we have acquired the knowledge of the work that others have done, we are prepared to make further progress, and if the difficulties and obstacles multiply we will be fairly equipped and fully encouraged to meet them. If we then experience failures, they will contribute to real advance instead of demonstrating a fact or law which had already been acknowledged,

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and which it was within our power and province to know. Thus too will indorsement of, and investment of capital in, prime movers, advertised as realizing fabulous power be avoided, since our knowledge of the laws of thermo-dynamics will have acquainted us with the principles of the conservation of energy, the impossibility of transgressing certain limits, and will, therefore, indicate or demonstrate the fallacies of the projected scheme.

In conclusion, I must say that I am aware that full justice has not been done to the theme under discussion, nor can, in my opinion, full justice be done to so grand a theme within the limits of a paper of this kind. A complete treatise would have to be written to demonstrate its true importance, and some work like that of Rankine is the best verification of the actual value of the science, and in its study does this value become most potently apparent.

But if I have been able to convince—say, one of you, heretofore uninterested, of the *vitality* of the study, I will feel amply compensated, and will offer no apology for my enthusiasm in the cause.

THE GEOMETRICAL INTERPRETATION OF IMAGINARY QUANTITIES.*

Translated from the French of M. Argand by Prof. A. S. Hardy.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

PREFACE.

THE work now republished† is of that small number which mark an epoch in the history of science. In this short treatise is found the germ of the true theory of so-called *imaginary* quantities. Although generally attributed to the genius of Gauss, this theory was not pointed out by that great geometer until twenty-five years after the publication of Argand's work,‡ and it had been meanwhile re-discovered several times in both France and England. On this point we can cite no testimony more convincing than that of a German geometer, whose recent death is deplored by science. Says Hankel,§ "the first to show how to represent the imaginary forms $A+Bi$ by points in a plane, and to give rules for their geometric addition and multiplication, was Argand, who established his theory in a pamphlet printed in Paris, in 1806, under the title '*Essai sur une manière de representer les quantités imaginaires dans les constructions géométriques.*' Yet this paper did not meet with public recognition until after the insertion of a note by J. F. Francais, in the *Annales de Gergonne*, Vol. IV, 1813, 1814, p. 61, in which, at the same time, Argand* also published two articles. In these articles the subject was so exhaustively treated that nothing new has since been found to add to them, and, unless some older work is discovered, Argand must be regarded as the true founder of the theory of complex quantities in a plane.

" . . . . In 1831, Gauss† developed the same idea, as is well known; but, however great his merit, as bringing this idea to the notice of science, it is none the less impossible to claim for him priority."

From this accurate historical *résumé*, it is seen that the work of Argand remained almost wholly unknown, having been distributed but to few persons, and not put in general circulation. Seven years later, Francais, an artillery officer at Metz, sent to the Editor of the *Annales* the outline of a theory whose germ he had found in a letter written to his brother by Legendre, the latter having obtained it from another author whose name he did not give. This article came to the notice of Argand,

* Essay on the Geometrical Interpretation of Imaginary Quantities, by R. Argand. Second edition with preface by M. J. Hoüel, and extracts from the *Annales* de Gergonne, Paris, Gauthier-Villars, 1874. From the French, by Prof. A. S. Hardy, Dartmouth College.

† 1st edition, Paris. Duminil-Lesueur, 1806.

‡ Anzeige zur "*Theoria residuorum biquadraticum Commentatio secunda*," 1831 (Gauss Werke, t. II, p. 174).

§ *Vorlesungen uber die complexen Zahlen und ihre functionem.* (Leipzig, 1867, p. 82).

* Vol. IV, p. 188, and Vol. V, p. 197.

† Works, Vol. II, p. 174,

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who immediately wrote Gergonne a note in which he made himself known as the author of the work cited in Legendre's letter, and in which he gave quite a complete summary of his pamphlet of 1806. This double publication gave rise to a discussion in the *Annales*, in which Francais, Gergonne and Servois took part, closing with a remarkable article, in which Argand explained more satisfactorily certain points in his theory, especially his demonstration of the fundamental proposition of the theory of algebraic equations, the simplest yet given, which subsequently Cauchy only reproduced, in a purely analytic, but less striking, form. These various articles, the natural sequel to Argand's pamphlet, published in a *Recueil* now very rare, are collected in an appendix to this volume. Notwithstanding their appearance in a scientific journal so well known, the views of Argand were wholly unnoticed, as appears from the fact that twenty-two years after the publication of the essay they were re-stated both by Warren, in England, and Mourey, in France, apparently without any knowledge on their part of their earlier exposition. Nor did they themselves succeed in attracting the attention of geometers, although the researches of Mourey were given in the *Lecons d'Algèbre* by Lefébure de Fourcy, and two articles, supplementary to his first work, had been published by Warren in the Philosophical Transactions. Only after Gauss had spoken, were these views taken up in Germany. They soon became familiar to English geometers, and were the starting point of Hamilton's theory of Quaternions, while, in Italy, Bellavitis made them the basis of his *Méthode des Équipollences.** In France, Argand's theory was worked over, without material addition, till its adoption by Cauchy, who expounded it in his *Exercices d'Analyse et de Physique mathématique*,† with a complete historical notice rendering Argand full justice.

In the work of this modest savant of Geneva is to be found the origin of many subsequent researches, some of which have thrown unexpected light both upon the mystery which has so long enveloped negative and imaginary quantities, as well as upon the general theory of functions, by affording a definite geometrical interpretation. Others, as yet of less importance, but perhaps destined in the future to render great services, have resulted in the creation of new methods in analytical geometry, among which may be cited those of Möbius, Bellavitis, Hamilton and Grassman. Unable to avoid the constant presence of negative and imaginary quantities in the results of analysis, or to surrender the important advantages following the use of their corresponding symbols, mathematicians had for a long time been content to employ them without fully accounting for their true nature, regarding them as signs of operations which in themselves had no meaning, yet which, under certain rules, led surely and directly, though in an obscure and mysterious manner, to results which other quantities would not have yielded, except indeed by long and difficult processes, involving the discussion of an indefinite number of particular cases. It is at last seen, however, that the impossibility of negative quantities is, in general, only apparent, and results from a generalization of the idea of quantity without any modification of the corresponding analytical operations. An analogous case is found in the very elements of arithmetic, which, however, has given rise to no difficulty. The operation of division cannot be exactly performed if we are restricted to whole numbers. But if unity be divided into equal fractions, the division is always possible, and the result becomes a *complex* expression, consisting of two numbers, one indicating multiplication, the other division. Hence arises a new class of quantities, fractions, subject to operations to which are applied the same names given to the operations on integers, which they include as particular cases. But the definitions of multiplication and division have been therefore carefully modified, to render them applicable to the new quantities. By proceeding in an analogous manner in addition and subtraction, the meaning of a negative quantity has been definitely fixed. So long as the problem is restricted to the simple determination of magnitude, the subtraction $a-b$ is im-

* *Exposition de la Méthode des Equipollences Guisto Bellavitis.* Traduit de l'Italien par C. A. Laisant, Paris. Gauthier-Villars, 1874.

† Vol. IV, p. 157.

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possible and absurd, if $b>a$. But if, instead of a series of magnitudes, extending from zero in a single direction, we are concerned with a series extending indefinitely in two opposite directions, and if we call *addition* an operation which consists in starting from a certain quantity in one of these two directions, and *subtraction* an inverse operation, consisting of motion in the opposite direction, thus defined, both operations will be always possible and their results as real as those of a purely arithmetical addition.

To represent these results in a simple manner, we are led to write before the symbol, representing any quantity, a sign indicating the direction in which it is estimated. Such is the true meaning of negative quantities.

This extension of the meaning of quantity and of the operations to which it is subjected, may be carried still further. But this further representation of quantity makes the use of a geometrical notation, which, within the limits of its application, is the most luminous and complete of all, almost indispensable. Suppose the quantity sought be subject to two causes of variation, and to depend upon two magnitudes which can be represented by any two co-ordinates fixing the position of a point in a plane. The operation of extracting the square root, for example, in the preceding case of a single variable co-ordinate, was possible only when the quantity so operated upon was of the kind denoted by plus unity. So long as $\sqrt{a}$ corresponds to the construction of a mean proportional between a and $+1$, $\sqrt{-b^2}$ indicates an impossible operation, and no point of the locus corresponding to a single variable co-ordinate can represent this result. But if both co-ordinates are made variable and the restriction to a single line be abandoned, and the definition of the extraction of the square root be modified, the case is otherwise. The quantities considered do not then depend upon a single magnitude, but on two, and are for this reason called complex quantities. In operating on such a quantity, both of the quantities on which it depends are affected, exactly as in operating on a fraction we affect its two terms. Thanks to the introduction of both new quantities and new definitions of operations, $\sqrt{-b^2}$ no longer indicates an impossible operation, and the term *imaginary* is no more applicable to such a result than to fractions or negative quantities. Such is the fundamental and immediate consequence of Argand's conception. Symbols of the form $a+b\sqrt{-1}$, to which all analytical results have been reduced, are no longer either impossible or incomprehensible; they are a system of two numbers a and b, which are combined with each other just as are the co-ordinates of a point in a plane. Thenceforth, the brilliant results of the powerful analysis of Cauchy were to be translated into a geometrical language speaking to the eyes, and the discussion of formulæ became a simple problem of the Geometry of Position, subsequently completely solved by Riemann. The theory of complex quantities which, by the discoveries of Cauchy, had become the basis of the theory of functions, thus received at the same time a new confirmation, placing them beyond all the doubt and objections to which they had been before exposed. Such are the eminent services rendered by the discovery of Argand both to Analysis and the Philosophy of Mathematics.

But geometry, as well as analysis, though to a less degree, has profited by the introduction of these conceptions, founded on the discovery of a new bond between these two branches of the science. In Argand's work are found the beginnings of a very general method of plane analytical geometry, developed later by M. Bellavitis with great success, furnishing a uniform process for the discussion both of problems in elementary geometry and the more advanced theory of curves. The advantage of this method consists in the introduction into the calculations of the points themselves instead of their co-ordinates, and the consequent choice at the last moment of the most convenient system of reference. Argand was less successful in his attempts to extend his method of representing points to space of three dimensions. Indeed, this problem involved difficulties far greater than those which he had just overcome, and not till after thirty years did Hamilton at last surmount them.

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We should have taken great pleasure in giving our readers some information relative to the author himself of this important tract. With this in view, we applied to M. R. Wolf, as more thoroughly acquainted with the history of science in Switzerland than any one else, and to whom we are indebted for a biographical collection, as remarkable for its profound learning as for its attractive style. M. Wolf at once kindly caused inquiries to be made in Geneva, Argand's native city. Unfortunately, the information he obtained, through Prof. Alfred Gautier, is contained in a few brief lines here cited: "I readily found the registry of birth, on July 22d, 1768, of Jean-Robert Argand, son of Jacques Argand and Éve Canac, very probably the author of the mathematical paper in question. I learn from one who knew his family that he was for a long time a book-keeper at Paris, and I presume that he died there. He was not a near relation of Aimé Argand, * and pernaps not of the same family. He had one son who also resided in Paris." M. Wolf subsequently learned that Argand also had a daughter named Jeanne-Francoise-Dorothée-Marie-Elizabeth, married to Félix Bousquet, with whom she went to Stuttgart, where he had obtained some unimportant situation. If we add to this that, about 1813, Argand lived at Paris, *rue de Gentilly, No.* 12, as indicated in his own handwriting on the cover of the copy sent to Gergonne, we shall have stated all we have been able to learn of this original man, whose modest life will remain unknown, but whose services to science Hamilton and Cauchy have deemed worthy the gratitude of posterity.—J. Houel.

1. Let a be any arbitrary quantity. If to this quantity another equal to it be added, we may express the resulting sum by $2a$. If we repeat this operation, the result will be $3a$, and so on. We thus obtain the series a, $2a$, $3a$, $4a$, ..., each term of which is derived from the preceding by the same operation, capable of indefinite repetition. Let us consider the series in reverse order, namely, ..., $4a$, $3a$, $2a$, a. As before, each term of this new series may be regarded as derived from the preceding by an operation which is the reverse of the former; yet, between these series there is this difference: the first may be indefinitely extended, but the second cannot. After the term a, we should obtain 0, but beyond this point the quantity a must be of such a nature as to permit our operating on zero as we did on the other terms . . . ., $4a$, $3a$, $2a$, a. But this is not always possible. If, for example, a represents a material weight, as a gram, the series . . . ., $4a$, $3a$, $2a$, a, o, cannot be extended beyond 0; for while we may take 1 gram from 3, 2 or 1 gram, we cannot take it from 0. Hence the terms following zero exist only in the imagination; they may, therefore, be called imaginary. But instead of a series of weights, let us consider them as acting in a pan A of a balance containing weights in the other pan also; and for the purpose of illustration, let us suppose the distance passed over by the arms of the balance is proportional to the weight added or withdrawn, which indeed would be the case if a spring were adjusted to the axis. If the addition of the weight n to the pan A moves the extremity of the arm A a distance n', the addition of the weights $2n$, $3n$, $4n$, ..., will cause this same extremity to move over the distances $2n'$, $3n'$, $4n'$, ..., which may be taken as measures of the weight in the pan A: this weight is zero when the pans are balanced. By placing the weights n, $2n$, $3n$ . . . ., in the pan A, we may obtain the results n', $2n'$ $3n'$ . . . . ., or, by starting with $3n'$ and withdrawing the weights, the results $2n'$, n', 0. But these results may be reached not only by taking weights out of the pan A, but also by adding them to the pan B. Now the addition of weights to the pan B can be continued indefinitely; and in so doing we shall obtain results expressed by $-n'$, $-2n'$, $-3n'$, ..., and these terms, called *negative*, will express quantities as real as did the positive ones. We, therefore, see that when two terms, numerically equal, have opposite signs, as $3n'$, $-3n'$, they designate the different positions of the balance arms, such that the extremity indicating the weight is in both cases equally distant from the point 0. This distance may be considered apart from *direction*, and be then called *absolute*.

* A friend and associate of the brothers Montgolfier, who invented the lamp of that name. (1755–1808.)

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Let us consider the origin of negative quantities in a case of another kind. If in counting a sum of money we adopt the franc piece as unity, we may operate successively by subtraction on this sum, and render it zero by taking away a certain number of francs. At this point the operation becomes impracticable, and, consequently,—1 franc,—2 francs, ... are imaginary quantities. Take now the nominal franc as unity, for the purpose of estimating a fortune made up of credit and debit. What we call a *diminution* of this fortune might take place either by a decrease in the number of francs on the credit side, or by an increase in the number on the debit side, and by continuing either process we should have a negative fortune of—100 francs,—200 francs, ... Such expressions signify that the number of francs of debt, considered abstractly, exceed by 100, 200, those of credit. Thus—100 francs,—200 francs, ..., which in the former case can express only imaginary quantities, here represent quantities as real as those denoted by positive expressions.

2. These ideas are very simple; yet it is not so easy, as it at first seems, to set them forth clearly, and to give them the generality which their application requires. Moreover, the difficulty of the subject will not be questioned if we remember that the exact sciences had been cultivated for many centuries, and had made great progress before either a true conception of negative quantities was reached or a general method for their use had been devised. Moreover, it was not our intention to endeavor to state these principles more rigorously or more clearly than they are to be found in the works which deal with this subject; but simply to make two remarks on negative quantities. First, that whether a negative quantity is real or imaginary,* depends upon the kind of magnitude measured; and, second, when we compare two quantities which are of a kind yielding negative values, the idea involved in their ratio is complex, including, 1° a relation dependent on number, considered *absolutely;* 2° a relation of *direction*, or of the sense in which they are estimated, a relation either of identity or opposition.

3. If now, setting aside the ratio of absolute magnitude, we consider the different possible relations of direction, we shall find them reducible to those expressed in the two following proportions:

$$+1 : +1 :: -1 : -1,$$
$$+1 : -1 :: -1 : +1.$$

Taken directly and by inversion, these proportions show that the signs of the means are alike or different when those of the extremes are so. Now let it be required to find the geometrical mean between two quantities of different signs, that is, to find the value of x in the proportion

$$+1 : x :: x : -1.$$

Here we encounter a difficulty, as when we wished to continue the decreasing arithmetical progression beyond zero, for x cannot be made equal to any quantity, either positive or negative; but, as before, the quantity which was imaginary, when applied to certain magnitudes, became real when to the idea of *absolute number* we added that of *direction*, may it not be possible to treat this quantity, which is regarded imaginary, because we cannot assign it a place in the scale of positive and negative quantities, with the same success? On reflection this has seemed possible, provided we can devise a kind of quantity to which we may apply the idea of direction, so that having chosen two opposite directions, one for positive and one for negative values, there shall exist a third—such that the positive direction shall stand in the same relation to it that the latter does to the negative.

4. If now we assume a fixed point K (Fig. 1) and the line KA be taken as positive unity, and we also regard its direction, from K to A, and write $\overline{KA}$ to distinguish it from the line KA as simply an absolute distance, negative unity will be $\overline{KI}$, the vinculum having the same meaning as before, and the condition to be satisfied will be met by KE, perpendicular to the above and with a direction from K to E, expressed in

* The sense in which these words are used is sufficiently determined by what precedes: the extension here given to their ordinary meaning seems permissible, and is moreover not wholly new. In optics, what is called the imaginary focus, as distinguished from the real, is the point of intersection of rays which have no existence, in a physical sense, and which can be considered, in some sort, as negative rays.

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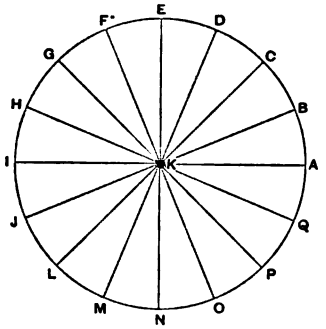
like manner by $\overline{KE}$. For the direction of $\overline{KA}$ is to that of $\overline{KE}$ as is the latter to that of $\overline{KI}$. Moreover we see that this same condition is equally met by $\overline{KN}$, as well as by $\overline{KE}$, these two last

Fig.1.



quantities being related to each other as $+1$ and -1. They are, therefore, what is ordinarily expressed by $+\sqrt{-1}$, and $-\sqrt{-1}$. In an analogous manner we may insert other mean proportionals between the quantities just considered. Thus to construct the mean proportional between $\overline{KA}$ and $\overline{KE}$, the line CKL must be drawn so as to bisect the angle AKE, and the required mean will be $\overline{KC}$ or $\overline{KL}$. So the line GKP gives in like manner the means between $\overline{KE}$ and $\overline{KI}$, or between $\overline{KA}$ and $\overline{KN}$. We shall obtain in the same way $\overline{KB}$, $\overline{KD}$, $\overline{KF}$, $\overline{KH}$, $\overline{KJ}$, $\overline{KM}$, $\overline{KO}$, $\overline{KQ}$, as means between $\overline{KA}$ and $\overline{KC}$, $\overline{KC}$ and $\overline{KE}$ . . . . and so on. Similarly we might insert a greater number of mean proportionals between two given quantities, and the number of constructions involved in the solution would be equal to the number of ratios in the required series. Thus, for example, to construct two means, $\overline{KP}$, $\overline{KQ}$, between $\overline{KA}$ and $\overline{KB}$, we should have the three ratios $\overline{KA} : \overline{KP} :: \overline{KP} : KQ :: KQ : \overline{KB}$, and necessarily, angle AKP=angle $\overline{PKQ}$=angle $\overline{QKB}$, the vinculum indicating that these angles are similarly situated with respect to the bases AK, PK, QK. Now this may be effected in three ways, namely, by trisecting 1° the angle AKB; 2° the angle AKB increased by 360°; 3° the angle AKB increased by twice 360°, giving the three constructions of Fig. 2, 2 bis, 2 ter.*

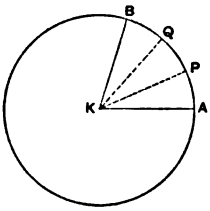


Fig.2.

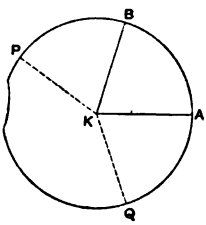


Fig.2.bis.

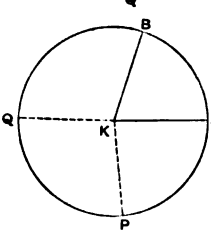


Fig.2.ter.

5. Observe, further, that the relations just established between the quantities $\overline{KA}$, $\overline{KB}$, $\overline{KC}$, ..., do not require that the directions which these quantities fundamentally involve should be estimated from a single point K; but that these relations are equally true for every such expression as $\overline{KA}$, indicating an absolute distance KA and taken in the same direction, as $\overline{K'A'}$, $\overline{K''A''}$, $\overline{K'''A'''}$, $\overline{BK}$, ... (Fig. 3). For,

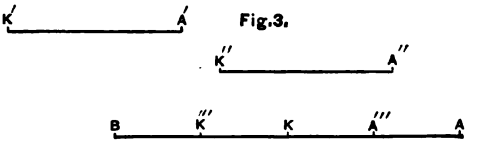


Fig.3.

following with respect to this new quantity the same reasonings as before, we see that if $\overline{KA}$, $\overline{K'A'}$, $\overline{K''A''}$, ..., are each positive unity, $\overline{AK}$, $\overline{A'K'}$, $\overline{A''K''}$,

* The principle on which these constructions rest, stated generally, is that the ratio of two radii $\overline{KP}$, $\overline{KQ}$, making an angle QKP, depends on this angle when these radii are considered as drawn in a certain direction, and that this ratio is the same as that of two other radii $\overline{KR}$, $\overline{KS}$, making the same angle; but although this principle is, in a way, an extension of that on which the geometrical ratio of a positive and negative line was established, it is here only an hypothesis whose legitimacy must be proved, and whose consequences, till then, are to be independently confirmed.

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are negative unities; that the mean proportional between $+1$ and -1 can be expressed by any line whatever, equal in length to the above and perpendicular to them in direction, and taken at pleasure in either of its two directions, and so on. To make this clear, consider a particular case as, for example, a given force assumed as unity and represented by $\overline{KA}$, acting parallel to KA in the direction from K to A, its point of application being arbitrary; this unit force may be expressed by a line parallel to KA, with any point as an origin. The negative unit would be an equal force with a parallel action line, but acting from A towards K, and could likewise be represented by a line drawn from any point parallel to the former one, but in an opposite direction. All that is necessary, then, to the application of the principles already developed regarding radii is that the qualities, indicated by plus and minus, which we attribute to a certain quantity, should depend upon opposite directions between which there exists a mean; and that the relations between all lines which will represent such a quantity be then conceived as the same which existed between the radii.

6. From these reflections it follows that we may generalize the meaning of expressions of the form $\overline{AB}$, $\overline{CD}$, $\overline{KP}$, ... , every such one representing a line of a certain length, parallel to a certain direction, the latter taken definitely in one of the two opposite senses which this direction presents, with any point as an origin; these lines themselves being capable of representing magnitudes of another kind. As they are to be the subject of the following investigations, it is proper to give them some special designation. They will be called *lines having direction*, or simply, *directed lines*.* They will be thus distinguished from *absolute* lines, whose length only is considered without regard to direction.†

7. Applying the terms of common usage to the different varieties of directed lines which arise in connection with a primitive unit $\overline{KA}$, it is seen, that every line parallel to the primitive direction is expressed by a real number, that those perpendicular to it are expressed by imaginaries of the form $\pm a\sqrt{-1}$, and, finally, that those having other directions are of the form $\pm a \pm b\sqrt{-1}$, and are composed of a real and imaginary part. But these lines are quantities quite as real as the positive unit; they are derived from it by the association of the idea of direction with that of magnitude, and are in this respect like the negative line, which has no imaginary signification. The terms *real* and *imaginary* do not therefore accord with the above exposition. It is needless to remark that the expressions *impossible* and *absurd*, sometimes met with, are still less appropriate. The use of these terms in the exact sciences in any other sense than that of *not true* is perhaps surprising.*

An absurd quantity would be one whose existence involved the truth of a false proposition; as, for example, the quantity x, satisfying at once $x=2$, $x=3$, whence $2=3$. The admission of such a quantity into the calculus would entail consequences as contradictory as $2=3$; but the results obtained from the use of the so-called imaginaries are in all respects conformable to those derived from reasonings in which only real quantities appear. We might thus foresee the impropriety of a nomenclature which classifies truly absurd quantities and the even roots of negative quantities together, and it was a consciousness of this impropriety which first gave rise to the ideas developed in this essay. It is thus that we are led to a new nomenclature.†

THE right of way for the first hundred miles of the Canada Pacific Railway has been purchased. It ends at the western boundary of the Province of Winnipeg.

[* The *directed lines* of Argand are, of course, Hamilton's vectors, and the above principle is simply a statement of the fundamental conception of a vector, *i. e.* that all quantities having direction as well as magnitude are vectors, and that vectors are not changed by translation without rotation.—TRANS.]

† The expression *lines having direction* is only an abbreviation of *lines considered with reference to their direction*. This remark will show that we do not pretend to create a new nomenclature, but, by this denomination, both to avoid confusion and secure brevity.

* There was a time, when led by the very nature of the case to admit negative values in the discussion of abstract quantities, geometers, having apparently some difficulty in imagining that *less than nothing* could be *anything*, applied to such values the term *fausses*. The use of this word, in its original vicious sense, ceased when the conception under which it arose was rectified.

† It is amost needless to observe that we refer only to the coufusion which arises from the terms, and that a corresponding confusion of ideas is not implied.

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MODERN STEEL AS A STRUCTURAL MATERIAL.

By Mr. W. Worby Beaumont, Associate Member Inst. C. E.

From Papers of the Society of Engineers.

THE object of this paper is not to bring forward any new experiments on the properties of steel as employed in constructive work, but to invite discussion on a few points which may occur to the engineer, to whom it seems desirable to consider the relative advantages of mild steels and iron in some mechanical or constructive work. For several years the substitution of steel for iron in various structural work has occupied the attention of engineers and metallurgists, but the progress which has been made, compared with the hopes that were entertained when steel made by the Bessemer process became cheap enough to make its cost, strength for strength, comparable with that of iron, has not been great. There are classes of structures in which a reduction in weight would be a material advantage, even when attended with an increased total cost. Ships, boilers, and girders may be instanced as examples. In this direction, therefore, engineers turned their attention, with a view to the application of steel. The difficulties, however, which attended the manipulation and connection of steel in structures largely composed of plates checked its application. Many failures attended the attempts to use it, chiefly resulting from apparently anomalous behavior of the metal under what were considered similar conditions, but more, perhaps, owing to the special treatment which it required as compared with iron. Those who had been long accustomed to the manipulation of iron were unable to depart from past practice sufficiently to operate upon the new material, with all the careful attention to its different properties which these demanded. Thus, although the difference in its behavior in the hands of the smith and plate worker, as compared with iron, was considered in several of the details of manipulation, certain other peculiarities were lost sight of in the assemblage of parts, which resulted in the destruction of work when almost completed. Even twenty years ago, before the modern cheap steels had been offered, steel made by the crucible process had been successfully employed on a small scale for boiler work. Very careful attention to the behavior of steel under treatment had no doubt been observed, as it might easily be on a small scale; but when, some years after, attempts were made to use Bessemer steel for boiler and bridge work difficulties arose, some of which were attributed to the nature of the material and some to the want of thorough care on the part of the workmen. Even when plates of this material cost more than iron for boiler construction, and very much more than iron for bridge and girder work, attempts were made to use it for the latter on account of the several advantages which would arise from a decrease in the permanent load of bridge structures. Failures, however, of parts of these structures both before and after completion, due to the want of the observance of the special treatment which the material demanded, discouraged its employment. The endeavors of steel makers during the past few years have, therefore, been directed to the production of steel possessing properties so far similar to wrought iron that no great departure from the methods of working this material need be made. Apart from the frequent want of uniformity in the mechanical properties of the Bessemer steel plates of a few years ago, it generally exhibited an absence of toughness, which not only made it difficult of manipulation in the hands of the plate smith, but caused its destruction after being built into a structure. Its uncompromising rigidity rendered it incapable of accommodating itself to, and gradually eliminating from, itself, the residual strains originating in unequal heating and cooling, and also to the unequal strains visited upon it by other parts of a structure, of which it

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was made to form a part, either by riveting or other modes of connection. It was not that the steel did not appear to possess the qualities when tested in the testing machine, but its behavior was apparently different when employed in full size pieces or plates, from that exhibited when tested in small pieces in the machine. This difference indicated that there were differential internal molecular strains resident in the whole plate which were eliminated when the same plate was cut into strips. This elimination, it was considered, could not take place in the whole plate on account of the harshness of its material. Annealing was resorted to, but only with partial success, the complex nature of the strains in a plate of the material, even when cooled slowly, being sufficient, when aggravated by extraneous strains to cause its rupture. It is perhaps not necessary here to consider the nature of the strains in a plate of iron or steel resulting merely from slightly differential contraction in cooling, but it may be observed that though small, these strains may have a material influence on the strength of a plate as a whole, and that they would be greater in the thicker plates. This may be referred to hereafter.

The necessity of imparting to steel plates the toughness characteristic of good wrought iron has thus induced steel manufacturers to devote their attention to the production of steel possessing great ductility. It is on this point that much might be said, because in the search for toughness the advantages which the employment of steel in some structures seemed at one time to promise, are being almost lost sight of. Not only are these advantages likely to be lost, but the great ductility being imparted to soft steels and ingot iron, in search for this necessary toughness, seems likely to give us a material inferior in some essential qualities to much of the wrought iron hitherto in use. Toughness in plates has not been obtained, but instead thereof great ductility attended with low elastic strength.

It may be premised that the structural value of a metal will be proportionate to the degree in which it combines high ultimate strength with high elastic limit and wide range of elastic and ductile extension, or in proportion to the relation in which it combines toughness with strength. Thus a metal which possesses high ultimate strength and high elastic limit, with small ranges of extension, will not have great structural value, as it will not be capable of withstanding impact strains. Again, a metal possessing high ultimate strength with low elastic limit will have small value for structural purposes, as, though high ultimate strength is an essential property, the limit of elasticity determines in almost all cases the sectional area, and, therefore, weight of metal required for a given duty. A high elastic limit, with considerable elastic extension, must be obtained, combined with great toughness beyond that limit, or in other words, a high elastic limit must be attended by a considerable range of extension both within and beyond that limit, combined with high ultimate strength.

The tendency, however, in the production of the modern mild steels and ingot irons, which will eventually no doubt supplant wrought iron made by the puddling process, is to make a metal which is far from combining these properties in such relations that it is best suited for structural purposes, or so as to offer those advantages which were at one time supposed to be attainable by the use of steel.

The best index to the comparative structural value of different materials is probably that obtained by the application of Poncelet's formulæ as simplified and made applicable for practical purposes by Robert Mallet. This formulæ expresses by coefficients $\frac{Te}{Te'}$ and $\frac{Tr}{Tr'}$ the work done by an extending or compressing force upon an elastic prismatic body, at the point where its elasticity becomes permanently impaired, and its form distorted, and at the further point where rupture occurs, or, in other words, it expresses the balance in any material between strength and toughness, and was designed to give a more exact index to the structural value of materials than was given by the early experimenters down to the days of Telford, when the force necessary to produce rupture was alone considered. The formulæ are probably known to most of the members

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of the society, having been given by Mallet in a paper "On the Coefficients of Elasticity and of Rupture in Wrought Iron," published in vol. XVIII of the "Proceedings" of the Institution of Civil Engineers, and subsequently employed by Dr. Pole in his book on "Iron as a Material of Construction," but they may be repeated here.

Let L = the length of the prism;
l = the unit of length;
A = the transverse sectional area of the prism;
i = the extension, or compression which is proportionate to $\frac{l}{L}$;
P = the force of extension or compression which is proportionate to A; and
e = the elastic resistance which balances P, or the modulus of elasticity.

The force P is, of course, variable between o and i,

$$i=\frac{PL}{eA} \text{ and } P=\frac{eA}{L}i.$$

If x be any small extension, or compression less than the nth part of i, P corresponding to $x=\frac{eA}{L}x$. The work done in extending, or compressing through the infinitely small additional range $\Delta' x$ (assumed uniform)$=\frac{eA}{L}x\Delta' x$, and the whole work done when i=the compression or extension at which the elasticity of the material is permanently changed, or the elastic limit reached, is

$$Te=\frac{eA}{L}\int_o^i x\Delta' x=\frac{1}{2}\frac{eA}{L}i^2,$$

or $Te=\frac{1}{2}ei^2$, or simply$=\frac{1}{2}Pi$;

for the unit of length and section. The value of the coefficient Tr is arrived at in the same way, by substituting the corresponding values for P and i due to the moment of crushing or of rupture. Thus for a material having under tensile strain an elastic limit P of 12 tons per square inch, and elastic extension e of 0.02 inch in a foot of length, and having an ultimate of 22 tons per square inch and a total extension of, say, 1 inch, the coefficient

$$Te=\frac{P\times 2240\times \frac{e}{12}}{2},$$

or

$$Te=\frac{12\times 2240\times \frac{0.02}{12}}{2}=22.31,$$

and

$$Tr=\frac{22\times 2240 \text{ by } \frac{1.0}{12}}{2}=2052.5,$$

while with another material having an elastic limit of, say, 14.22 tons, elastic extension 0.024 inch; ultimate strength, say, 23 tons, and total extension of 1.6 inch in a foot, the coefficient Te=31.8 and Tr 3501.

In order to determine the relative structural values of several materials, it is thus necessary to take Te and Tr simultaneously into consideration, though Te is the coefficient of the greater importance in most structural work.

About a dozen years ago Bessemer metal was offered for bridge and ship construction, which in the testing machine showed an ultimate tensile strength of from 34 to 40 tons per square inch; an elastic limit from 20 to 23 tons, and a range of ductile extension of from 10 to 18 per cent., while the tests of plates considered suitable for the shells or barrels of boilers showed figures not much lower than these. The failures which occasionally attend the application of this steel, however, discouraged the extension of its application by engineers, who hoped that greater uniformity in the mechanical properties of the metal would gradually be obtained by the steel makers. A steel of somewhat lower tenacity and greater ductility, attended by great uniformity in composition and behavior, was then produced, and this indicated that steel makers and engineers must look to steel of milder character for the removal of the difficulties which had attended the structural application of cheap steels, that is, steels not produced by the crucible. The result of this was that engineers specifying steel for, say, bridge-work, stipulated that it should not possess more than a certain maximum tenacity, a reversal of the stipulation that had always and does obtain with respect to iron. As a further result of this, and to ensure that the

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harder steels of comparatively high tenacity, but less uncertain character, should not be used in the construction of bridges, the Board of Trade regulations upon the subject limited the tensile strain on any part of a structure to 7 tons per square inch. This has led to the endeavor on the part of all steel makers to produce the very mild soft steels now largely used, some of which afford the engineer no help towards producing the lighter structures which a dozen years ago it was promised that steel would give them. Boiler shells must be made nearly or quite as thick as if they were constructed of iron.

As an instance in illustration reference may be made to the results of a series of experiments made on iron and mild steel, in order to determine their respective values for high-pressure boiler construction, and described by Mr. David Greig and Mr. Max Eyth in a paper read before the Institution of Mechanical Engineers, in June, 1879. Amongst other experiments, the mechanical properties of mild steel and Yorkshire plates under tensile strain was determined. The plates—both iron and steel—were obtained from Messrs. John Brown & Co. and Messrs. Cammell & Co. In the paper referred to the mean tensile strength, elastic limit and extension are given as follows:

	Ultimate strength. Tons per square inch.	Elastic limit.	Extension per cent.
Iron plates.....	22.27	16.06	36.2
Steel plates....	25.80	16.74	28.3

The extension given is in a length of 6 inches. If all reference to the secondary elastic limit, which may be induced by repeated application of strain up to and slightly exceeding the elastic limit of each preceding test, be omitted, it will be seen that the so-called steels, to which the above figures relate, present scarcely any structural advantage over iron. The elastic limit is nearly the same, and though its ultimate strength is greater than that of iron, its ductility, as shown by its range of extension, renders its greater ultimate strength of little value; for very long before it can be strained to that limit, in any structure, it stretches so much that the accumulation of strain is prevented, and this may be shown to take place in bridge as well as boiler structures. With respect to the latter, Messrs. Greig and Max Eyth observe that "the tensile and shearing strength of the material supplied for these tests by some of the most experienced makers of steel, and by them, no doubt, considered the best for the purpose, has in the experiments proved to be not more than 10 per cent. above that of the iron supplied at the same time, and its want of hardness, as distinct from tensile strength, has proved to be a very serious disadvantage in boiler work. What the trade now requires is a return to a harder material of increased tensile strength without losing the homegeneity which is as present obtained at the expense of hardness." Again, in speaking of the results of the test, under hydraulic pressure, of the complete boilers made of this steel, they say, "the compression of the rivet and elongation of the rivet hole resulted invariably in leakage which prevented the necessary pressure from being obtained. Each rivet became its own safety valve, and the strain put on the weakest part never reached more than 70 per cent. of the breaking strain. This is the point where additional hardness of the material would be most useful, as it would prevent the opening of the rivet holes, which now makes a boiler useless long before the breaking strain is reached." This evidence is, therefore, to the effect that no structural advantage is obtained by the use of these steels in place of iron.

If we turn now to the result of tests, made by Mr. Kirkaldy, of Siemens' mild steel, we find that the mean results for plates of from 0.37 to 0.70 in thickness, annealed and unannealed are as follows:

	Ultimate strength. Tons per square inch.	Elastic limit.	Extension. per cent.
Unannealed....	31.02	14.50	23.4
Annealed.....	28.84	12.84	24.6

From these figures it will be seen that though this material (like that used at Messrs. Fowler's Works) may be very safe, it presents little structural advantage over iron plates, the limit of elasticity being low, permanent set taking place at as low as 12.84 tons per square inch when the plates are annealed. It is, however, observable that though the extension of this metal reaches a total of 24.6 per cent. it is less than 11 per cent. annealed, and under 7 per cent.

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unannealed at a strain of 26.78 tons, thus indicating very considerable toughness and probably greater value as a structural material than that tested by Messrs. Greig and Max Eyth.

Material described still more recently gives the engineer even less of hope that the modern steel for structural purposes will enable him to produce lighter structures than he can do with iron. It would even appear that greater hope of obtaining a material of high structual value is to be found in iron; for it was recently stated at a meeting of the Iron and Steel Institute by a member that he had been experimenting with puddled iron, the elastic limit of which ranged from 19 to 20 tons, while its ultimate strength was 29 tons and its elongation between these strains was 23 per cent. in a length of 8 inches. The elongation within the elastic limit was not mentioned. Unless a higher elastic limit can be obtained no advantage in a structural sense is secured. High ultimate strength is a comparatively useless quality if the elastic limit is low, and great range of extension is also of no service. In bridge work a very high range of extension is useless, because the members under tension would elongate if strained beyond the elastic limit, to a greater extent than the members under compression would compress, and thus the structure would fail by the destruction of the balance in the disposition of the strains on the different parts. Even if the material showed a range of compression equal to its range of extension this would remain equally true, because in order to secure the necessary resistance to bending or buckling, members under compression must be of greater sectional area than is indicated by the static strain. Thus a higher elastic limit is the first essential in steel for structural purposes. This it appears can only be obtained by making the steel harder, which, by the Bessemer process at least, if not by other largely used processes, it seems cannot be secured without other attendant qualities or properties which make the material difficult to work, and more or less uncertain in its behavior under mechanical treatment. Whether this is really now so, or must continue so, it remains for the steelmakers to show, but it does at least seem plain, that even with some of the so-called mild steels a little misgiving is pardonable on the part of the boilermaker, who wonders what he may find in a boiler shop to-morrow where he has left a nearly or quite finished boiler to-night. Not only, moreover, is this mild steel way of getting over the difficulties attending the use of the strong steels likely to rob engineers of much that the latter material promised; but by the still existing custom of denominating what is really iron by the term steel, we are like to lose the advantages gained by using the harder steels where that has been possible, for already a good deal of so-called steel, in which there is not much more carbon than there is in a Lowmoor bar, is being worked up into steel rails and steel tires. It is true that rails of very hard steel do not wear quite so well as those of a tougher quality, but it remains to be seen whether some of the very mild metal being rolled into rolls to-day may not soon acquire battered heads under the heavy traffic of modern locomotives. Such rails will not laminate, but it remains to be seen whether splitting will not result from the deformation by battering.

It will have been observed that in this short paper the attention of the writer has been almost wholly confined to references to plates. This has been done because chiefly in plates improvement has to be looked for from the steel makers. With bar steel, the difficulties in manipulation and connection in structures have not been so great as with plates, and failures, whether due to imposed or internal differential molecular strains, have not been so frequent; sections are less in area and forms less capable of initiating and transmitting destructive strains. Consequently, mild bar steel need not be so ductile as mild plate steel, and hence the structural value of mild bar steel is much higher than that of plates, and engineers can use it to advantage. In the course of a very interesting lecture delivered by Dr. Siemens at the Royal United Service Institution in March, 1879, he gave a table showing the results of a serious of tests of mild and hard steel bars up to, and slightly beyond their elastic limit. This table is of great value as affording evidence of the structural value of these

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bars, and it is to be greatly desired that similar observations should be made on all kinds of modern metallic structural materials. The mild bars to which Dr. Siemens' table refers shows a mean elastic limit of 17.37 tons when annealed, though the same bars showed the lower mean elastic limit of 16.62 before being annealed, and curiously the elastic extension is also greater in the annealed bars, the mean extension in bars 5 feet 0 inch, and 4 feet 11 inches, being 0.086 inches, the value of the Te of the bars being by the before-mentioned formulæ, respectively 57.04 and 53.348. This denotes a high structural value, although this indication must be taken with the value of Tr which cannot be gained from the table referred to. Such materterial, however, is not to be had or cannot be safely used in plates, and even in bars has been very little used in bridgework. Steelmakers have yet to satisfy engineers that it can be safely used.

The most of the recorded experimental results of tests of mild steels do not give the extension of the elastic limit, so comparisons with other materials cannot at present be made. From what has been said, however, it will have been seen, that it is very necessary that these figures should be obtained, and what has often been observed may be here repeated, namely, that in order to the production of a satisfactory series of tables of the mechanical properties of different structural metals, experiments should be conducted on a uniform basis, and with uniform lengths of tests pieces, or if not of uniform length, they should be of a minimum length of either ten inches or one foot.

Such experiments would be perhaps costly, but there is at least one wealthy engineering society, by a committee of which such experiments might be usefully carried out on the structural materterials of to-day.

In conclusion, a few words may be said upon the behavior of the harder kinds of steel plates in which they differ from those of iron. It has been observed by many that some of the steel plates with an elastic strength as high as 18 tons per square inch combined with a ductile extension as high as 15 per cent., as obtained by the tests of strips of such plates, that in the hands of plate smiths or when built into structures, they behave very differently to iron with the same apparent mechanical properties. The toughness of good iron plates enables them gradually to dissipate any internal differential molecular strains of tension and compression that may be resident in them as they leave rolling mills, by differential compression and tension. Steel plates which are comparatively hard, but which, when torn asunder in test-strips, indicate an ultimate extension of as much as 15 per cent., might be expected to do the same. Such, however, is not the case, for the plate has often behaved, when built up into a structure, as though its ultimate extension was not more than one or two per cent., and, like glass, possessed of a high elastic limit, but no toughness. Why this should be is not known, but it may be suggested that such being the behavior, the following may afford some clue to the fact that thick plates, at least of such material, have fractured in various directions, after the structure of which they have formed an integral part has been completed. Most plates before being built into a structure are annealed, but the following remarks apply equally whether annealed or not.

Plates when taken from the rolls or from the annealing oven are generally laid on a flat surface to cool, but whether laid down or stood on edge, cooling takes place somewhat more rapidly towards the corners and edges than at the middle. At first, the whole plate is of the same temperature, which may be that of redness. The exterior parts first assume the rigidity of cold iron, and contraction takes place on the interior parts which remain at a higher temperature, and therefore the contraction has taken place under a tensile strain. Thus, if a plate of 1 inch in thickness is considered in illustration, it will be seen that a corner of, say 6 inches on either edge, has an area on the two sides of 36 square inches, but it has also the additional effective cooling area of the edges, which adds 12 square inches, making for a surface area of 36 square inches a total of 48 square inches of effective cooling area by radiation and evection. If, on the other hand, an area on the two sides at the center of the plate, of 36

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square inches of such surface, be taken into consideration, it will be seen that the edge surface can only be considered as cooling by conduction. Thus, the effective cooling area of the outer parts of the plates is much more efficient than the central parts. These outer parts having, then, become rigid and contracted under tension, exert a corresponding compressive strain upon the interior parts still at higher temperature and thus more or less amenable to compression. This tensile strain upon the outer parts or borders of the plate is gradually eliminated as the interior parts cool, and is finally changed into one of compression, as the inner parts contract in cooling under a molecular tensile strain, due to the incapacity of the rigid border to follow the inner parts in their contraction. In the cold plate put into a structure, there is thus initial molecular strain differentiating from compression at the edges to tension towards the center. If the plate is cooled under circumstances inducing unequal cooling these internal strains are aggravated, and they may possibly be of such magnitude that extraneous strains, that would not materially affect a tough iron plate, may be sufficient in a hard steel to cause rupture. Further, when a plate of such a character is being riveted up, every rivet is compressed under a very high strain to make it fill the holes, and thus, acting as a viscous fluid, adds to the strains already tending to destroy the plate.

These remarks are only made as suggestions, and should perhaps have been put in the form of a question, as they are somewhat aside the object of this note, which is to invite discussion on what seems to be the tendency in the production of very mild steel plates, namely, that in the endeavor to remove the difficulties which have attended the use of steel plates of high elastic limit, we seem to be in danger of losing the facilties for producing lighter structures which the application of steel seemed at one time to afford.

THE STRENGTH OF BOILER FLUES.

From "The Engineer."

VERY high pressures are now carried at sea on the outside of tubes of comparatively large size. These tubes are the cylindrical furnaces of marine boilers, and reach in some cases a diameter of 4 ft. It is of the utmost importance that very definite rules should be laid down for the guidance of those who design such furnaces, in order that no mistakes may be made. We say "definite rules," because the whole subject has been fully investigated. There is apparently nothing more to learn about it, and there should, therefore, be no trouble in constructing a simple formula which would enable an engineer to tell, with very little calculation, what is the proper thickness for a furnace tube of any given length and diameter, intended to sustain a stated pressure. Something of the kind will be found in almost all treatises on steam boilers. The practice thirty years ago was to treat the flues as though the pressure were to be exerted inside of it. The pressure was to be found by the well-known rule $p=\frac{2st}{d}$, where s is the strain in pounds per square inch to which the iron is to be subjected, t the thickness of the plate, d the diameter of the boiler, and p the working pressure. Then the proper thickness for flues was half that which would suffice for a shell. This practice is, we are happy to say, no longer followed. It answered fairly well while moderate pressures not exceeding about 45 lbs. on the square inch were used, but it was totally unfit to deal with such pressures as are now carried at sea and on land. Wilson gives the following formula for the strength of flues: $p=\frac{262.4\times t^2}{l\times d}$ where p is the collapsing pressure in pounds per square inch, t the thickness of tube in thirty-seconds of an inch, l the length in feet, and d the diameter in quarter feet;

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other rules may be found in other treatises. Fairbairn has shown that the strength of a flue to resist collapsing pressure varies directly as the 2.19 power of the thickness, and inversely as the diameter and length. Thus:

$$P = 33.6 \times (100t)^{2.19} \div L \times d$$

and $p = 5.6 \times (100t)^{2.19} \div L \times d$.

These are very ungainly formulæ, and useless without logarithms. It may not be superfluous to say here, however, for the guidance of those who would like to use Fairbairn's rules as a check on their own practice, that in using the formulæ the thickness of the plate is to be multiplied by 100. The log. of the result is to be found and multiplied by 2.19. This gives a log. the natural number of which is the 2.19 power of $100t$.

It is not to be supposed that the Board of Trade, which is so precise in its instructions and rules for marine engine builders, would allow this subject to pass without consideration. Accordingly the Board has proposed a rule, which runs thus: $p = \frac{60{,}000t^2}{(l+1) \times d}$. Here 60,000 is a constant for furnace tubes with longitudinal seams, lapped joints, and punched holes, single riveted; l is the length of the furnace in feet; d is the diameter in inches; and p the working pressure. To illustrate the application of this rule, let us suppose that a furnace is 40 inches in diameter and 7 ft. long, and that the plates are .375 inches thick. Then $\frac{60{,}000 \times .140625}{(7+1) \times 40} = 26.3$ lbs. as the working pressure. But the Board of Trade rule is not the only one with which engineers have to deal. "Lloyd's" have a rule also, which is, $p = \frac{89{,}600 \times t^2}{l \times d}$. Applying this rule to the furnace whose dimensions we have just stated, we have $\frac{89{,}600 \times .140625}{7 \times 40} = 45$ lbs. We thus find that one great authority on marine engineering allows nearly twice as great a pressure to be carried as the other. If the Board of Trade be right, then Lloyd's must be wrong, and dangerously wrong. If, on the other hand, Lloyd's are right, then the Board of Trade behaves very vexatiously and insists on a much lower pressure being carried than is necessary. Before any opinion on this point can be properly pronounced it is necessary to call in some other authority. Referring to the tables given in Wilson's treatise on steam boilers, we find that the collapsing pressure of a flue 7 ft. long, $\frac{3}{8}$ inch thick, and 40 inches in diameter is nearly 400 lbs. on the square inch. Lloyd's factor of safety is consequently about 9 to 1, while the Board of Trade factor is nearly 15 to 1. If one margin be enough then the other must be too great.. In dealing with this part of the question we can only arrive at anything like a satisfactory conclusion by resorting to the result of experiment. Mr. Wilson's figures refer to very perfect tubes, such as may or may not be met with in practice. Mr. D. K. Clark has investigated many cases of collapsed tubes, and he has prepared the following formula:

$$p = t^2 \times \left(\frac{50{,}000}{d} - 500\right).$$

Applying this rule to the case stated, we have 105.4 lbs. as the collapsing pressure. In this case the Board of Trade factor of safety is nearly 4 to 1, and Lloyd's factor is a little over 2 to 1. It must be remembered, however, that Mr. Clark's rule applies to flues of considerable length without any strengthening rings; to these he has attached no precise value. But it may be taken for granted that a marine boiler furnace tube well secured at each end and not more than a few feet long, is very much better able to stand up against a collapsing strain than a tube 25 ft. or 30 ft. long. We may, we believe, take a mean between Mr. Wilson s figures and Mr. Clark's, and assume that the collapsing pressure of our tube would be about 200 lbs. on the square inch. Under these circumstances Lloyd's formula gives a factor of safety of 4.4 to 1, while the Board of Trade rule gives 7.7.

Now, it is evident that the disparity between the rules of the Board of Trade and of Lloyd's ought not to exist. It places engineers and shipowners alike in a very unpleasant position, and will some day cause a good deal of trouble. A case may be cited which recently occurred. Two wing furnaces on board a

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North-county steamer collapsed with 20 lbs. of steam pressure and plenty of water. The collapsed flues are round topped, with flat stayed sides, and by the Board of Trade rules, the working pressure was 22 lbs. and by Lloyd's 42 lbs. It is probable that when the case comes to be investigated it will be found that the metal was either over-heated by the presence of deposit, or that the flues were worn. Be this as it may, it is not inconceivable that the engineers of the Board of Trade and those of Lloyd's may some day come into collision in a court of law over such questions, and we shall then have anything but an edifying spectacle presented for consideration.

The engineers of a great public department asserting that a boiler is strong enough, while those of the Government assert that it is too weak, will not be a satisfactory display in any sense of the word. The question at issue is one really of very great importance to engineers and shipowners. Is it too much to ask in the interests of common sense that the two bodies should put themselves in communication and agree on so apparently simple a matter as the preparation of a rule for the thickness of furnace tubes?

INFLUENCE OF TEMPERATURE IN TUNNELING THROUGH HIGH MOUNTAINS.

By DR. F. M. STAPFF.

Translated from Revue universelle des Mines, for Abstracts of Institution of Civil Engineers.

As the difficulties encountered from elevated temperature in tunneling through high mountains require the adoption of appliances and resources very different from those hitherto employed, the author, as Engineering Geologist of the St. Gothard Tunnel, Airolo, has during the past six years been collecting voluminous materials for the purpose of endeavoring to solve the two following questions:

1st. What is the highest temperature at which men can work underground?

2nd. At what depth below surface is this temperature likely to be reached in tunneling?

I.—*Temperature at which underground work becomes impossible.*—The limit of heat at which men can work depends upon the length of their exposure to it, the amount of exertion they put forth, their acclimatization, the nature of the atmosphere, and, most of all, its degree of moisture. Omitting instances of momentary exposure to exceptional heat, it is certain that men cannot accustom themselves to stand for any length of time more than 60° to 75° Centigrade or 140° to 165° Fahrenheit, even when keeping perfectly still and in quite pure air. In the author's experience on mining and railway works in Mexico and the south of the United States the temperature was as high as 40° C. or 104° F. In tropical seas the temperature in the stoke-holes of steamers occasionally reaches even 69° C. or 156° F., and is aggravated by the dust raised in the act of stoking. Unfortunately there is not sufficient information at present available as to the practicable limits of temperature in underground workings. In upcast shafts used for winding, and for raising and lowering the men, a temperature of from 27° to 32° C. or 80° to 90° F. is allowed for the air current in English collieries; and in Belgian from 22½° to 34½° C. or 72° to 94° F. At Fahlun copper mine in Sweden, in reopening some old workings that had been stopped by a fire twenty years previously, the clearing up was done at a temperature as high as 52° C or 125° F.; but there the natural ventilation was excellent. In another mine, stoping was abandoned at a temperature of 33° C. or 91° F., where the dust from the decomposed pyrites was more intoler-

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able than the mere heat, and dyed the miners as black as ink.* The highest temperature observed in the Mont Cenis tunnel was 30° C. or 86° F., at about 4 miles in from the south end. In the St. Gothard tunnel full work was carried on at about 31° C. or 87° F. on the south (Airolo) side, in air surcharged with moisture; and on the north (Göschenen) side at 29° C. or 84° F., in an atmosphere not quite saturated. The author gives detailed particulars of the air-supply to each end of the tunnel, and of the number of men, animals, and lamps consuming it; and on the assumption that the dryness of the air is of equal importance with its purity, he deduces the ratio of 4 to 3 as about representing the superior ventilation of the northern section over the southern at the time of his observations, when each end had been driven about 4 miles in.

According to Professor Dubois-Reymond of Berlin, men can stand 50° C. or 122° F. when the air is as dry as possible, as in the case of blast-furnace workers; but in an atmosphere saturated with moisture even 40° C. or 104° F. would almost certainly prove fatal. Air feels very dry when only one quarter saturated, but becomes stifling before complete saturation is reached; hence a slight diminution of moisture may be of the utmost value, and the principal means of rendering high temperatures endurable would consist in drying the air. A wagon-load of quicklime, notwithstanding the heat evolved in quenching, he considers would even give a fresher feeling than one of ice, on account of the latter rendering the air still more moist. If at the working place there were both a wagon of lime and one of ice, and also a supply of fresh air direct from the tunnel mouth, he is of opinion that work could be carried on even where the temperature of the rock was as high as 50° C. or 122° F. The ice would indeed be far more efficacious if covered with a layer of common salt, whereby not only would the temperature be still further lowered, but also increase of moisture would be prevented. The men would have to work short shifts, and the heat of the body should not reach 40° C. or 104° F., the ordinary bodily temperature being from 36¾° to 38° C. or 98° to 100° F.

The Author goes minutely into the effects observed to be produced upon the health of the men employed in the St. Gothard tunnel. He also reports at length a number of observations he made, as to how hot the men got, and how much work they could do, according to the state of the air in the tunnel. The diminished effort instinctively exerted by them, in proportion as they get hotter from the heat and badness of the air they breathe in such situations, is shown to be in accordance with physiological principles. Taking as the unit of bodily exertion the amount of effort put forth in merely walking along the tunnel at an easy pace—say about 4,550 foot-lbs. per minute—the Author considers this is somewhat exceeded by the ordinary exertion of the workmen employed in the roomier portions of the tunnel, behind the advanced heading. Those engaged, however, in loading the broken rock into the wagons near the forebreast, in the confined space of the advanced heading itself, must in his opinion, judging from the shorter time they work and the higher rate of their wages, be working about twice as hard; and occasional intermittent efforts may be even four times as great. They have to fill the broken stone into baskets upon long narrow lorries running on temporary rails of 1 foot guage, laid alongside the main rails of 3½ feet guage; the lorries have to be run back by hand through a distance averaging about 80 yards to the main trucks, into which the baskets have then to be emptied. A score of men formed the gang occupied in this heaviest work. The relative cost of the clearing per cubic yard of rock in the two headings is found to be represented by the very same ratio as the absolute moisture of the air in them, namely, 1 to 1.18 in the Göschenen and Airolo ends respectively.

The highest limit theoretically possible for the air temperature in tunnel workings would be such as would induce fever

*In the last working of the United copper mines in Gwennap, Cornwall, a hot spring of water at 115° F. was met with in the bottom level about 1,500 feet below surface, and the rock was so hot that even with their thick clothing the miners could not lean against it. (See Proceedings Institution of Mechanical Engineers, 1873, p. 110.) In the Comstock silver mines, Nevada, the temperature averages 130° F. at about 2,000 feet below surface, and sometimes reaches 139° F., while in particular places even 157° F. has been observed. (See Transactions American Institute of Mining Engineers, vol. vii., pp. 45-76; and Minutes of Proceedings Institution Civil Engineers, vol. lvii., p. 393).

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heat, of 42° C. or 107° F. in the body; while the extreme practicable air temperature, still not free from the certain prospect of impaired health and premature death, would be that under which the heat of the body should not rise above 40° C. or 104° F. The latter limit being applied to the atmospheric conditions affecting the two ends of the St. Gothard tunnel, the Author calculates that the practicable limit of air temperature should not exceed 45¾° C. or 114° F. in the Göschenen end, and 37¾° C. or 100° F. in the Airolo end, for the laborers clearing the advanced headings. He adds, in a tabular form, the corresponding figures for assumed cases both of harder and of easier work than that of removing the spoil from the ends of these particular headings.

II.—*Limit to Depth of Tunnel below Summit of Ridge.*—The scale for increase of temperature with depth, which obtains in mines and bore-holes sunk below level ground, is inapplicable to mountains, owing to the cooling effect of their exposed sloping sides. From Borelli's temperature observations in the southern portion of Mont Cenis tunnel, Ansted deduced an increase of 1° C. per 50 meters, or 1° F. per 91 feet depth below the summit of the mountain profile over the line of the tunnel; but that rate did not hold good for lower elevations in the same profile, and was therefore not applicable as any guide for other tunnels. From his own observations in the St. Gothard tunnel, from 1873 to 1877, for distances of 4,800 yards in from the northern mouth and 4,500 yards in from the southern, the Author deduced empirical formulæ for the temperature to be expected during the further progress of the work. These having been found to hold good for the 2,000 to 3,000 yards next driven, he now reproduces some of the principal. For the temperature of the rock itself, the general average result in its simplest form is an increase of 1° C. per 48.4 meters, or 1° F. per 88.1 feet of vertical depth below the surface of the mountain. This scale gives too low a temperature for parts of the tunnel that are under valleys and plains on the mountain sides, and too high for parts under peaks; the variations from the actual temperatures noted at individual points in the tunnel amount to nearly as much as 5° C. or 9° F. But, for the mean temperature throughout any considerable length of the tunnel, the calculated result agrees exactly with actual observation, however varied be the mountain profile overhead. In confirmation the Author reproduces from the St. Gothard Company's eighth report a Table of observations made in 1878 through 1,500 yards' length of the southern half of the tunnel, between 5,000 and 6,500 yards in from the mouth. The variations of mountain profile may even have the effect of producing a practically uniform temperature for miles of tunnel, notwithstanding hundreds of yards difference in the heights of rock overhead. For the temperatures to be expected at the middle of the tunnel, the minuter calculations are given which had been made last year by the Author, at the time when each end had been driven about 7,700 yards in, leaving then about 1,000 yards intervening to be driven. His estimate, with a margin for error of ± 2½° C. or 4½° F. was 31¾° C. or 89° F. for the rock; the same for the air about 150 yards behind either forebreast, prior to the two drivages holing through into each other; and 33¾° C. or 93° F. for the water issuing from the rock. In March, 1880, after the holing through, the actual mean temperature of the rock for the middle length of 1,000 yards was found to be 30½° C. or 87° F.; and this was also the air temperature 150 yards behind the forebreasts prior to holing through. At the two forebreasts themselves the air temperature was brought down as low as 27¾° C. or 82° F. while boring, and 30° C. or 86° F. while clearing away spoil: which was about 3° C. or 5° F. lower than calculated, the reduction being due to an extra supply of compressed air during the last 1,000 yards' drivage. These several temperatures, though high enough to retard the progress materially in the middle of the tunnel, and render the work more laborious, was not so excessive as to entail either stoppage or danger.

General Remarks.—Having entered minutely, and at great length, into the various conditions affecting the execution of the work in the two ends of the St. Gothard tunnel, the author refrains from attempting to lay down a fixed limit, either of temperature or of depth, for

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any future tunneling operations which may enjoy the advantage of resources superior to those hitherto available. But the means to be employed for dealing with higher temperatures than have hitherto been encountered would have to be very carefully matured beforehand, both theoretically and practically.

Projected Simplon Tunnel.—The extent of guidance, furnished by the light of present experience, is illustrated by the author's application of his calculations to the principal projects for tunnelling through the Simplon. Of the longer routes plotted, for piercing the mountain nearest its base, from near Brieg on the northern slope, those of MM. Favre & Clo, and M. Lommel, each nearly 12 miles, would appear to be impracticable of execution with the resources at present available. According to their mountain profiles, the depth of these tunnels below the ridge would be about 7,300 feet; whence the temperatures to be expected midway in the tunnels would be about 47° C. or 116° F. for the rock, and for the air 150 yards behind the forebreast, and about 53° C. or 127° F. for water issuing from the rock. In the shorter and higher tunnel proposed by M. Stockalper, about 10 miles long, piercing the range at about 2,560 feet above sea-level and beneath a rather lower portion of the ridge, the author estimates the depth below the ridge at about 5,900 feet, and the rock temperature midway in the tunnel at about 40° C. or 104° F.; here therefore the extreme limit of practicable execution would be reached. In two still shorter and higher tunnels, each about 7½ miles long, proposed by MM. Clo & Venetz, and M. Jacquemin, the temperature encountered would be much the same as has been met with in the St. Gothard tunnel; but their greater height above sea level would somewhat detract from the value of both these tunnels, as compared with those nearer the foot of the mountain.

Selection of Route.—Supposing its height above sea level be already determined by commercial or political considerations, the route selected for a tunnel should be such as to offer the greatest facilities for its execution. In the case of the St. Gothard tunnel, it was pointed out by the author in 1877 that, if the route had lain 1 mile or 1½ miles westward, it would have been attended with several advantages, which he here recapitulates. It is not so easy from surface indications to form an idea about the quantity of water likely to be met with, and the solidity of the rock to be driven through, as it is from the height and contour of a mountain to calculate the increase of temperature likely to be encountered. The principles long established by general mining experience may, however, be properly applied to tunneling; and in the longitudinal sections compiled by the author for the St. Gothard tunnel, it is seen how the surface indications held good down to that depth: fissures, slides, and faults, noted on the mountain profile, severally made their appearance without fail in the tunnel, most of them in a very unwelcome manner. A recent illustration from near the middle of the tunnel is cited. The author thinks it safer and easier to avoid difficulties of this sort by careful selection of route beforehand, than to try to get over them afterwards during the execution of the work. For the projected Arlberg tunnel in Austria, he is glad to find the route laid down with a view to avoiding, by a curved course, rock that seems likely to let out streams of water. Tunnels through high mountains should, as far as possible, be driven in places where they will have the least height and bulk of mountain overhead, and where they will be likely to be most free of water.

Mode of Driving.—The mode adopted for driving the St. Gothard tunnel is not considered by the author, from the experience there gained, to be the most eligible for long tunnels, where not more than two ends can be driven, and these not faster than a certain limit of speed, and where it is impossible to foresee all the difficulties that may arise. In respect of the atmosphere pervading the working places, that mode of driving seems indeed decidedly objectionable. In the St. Gothard tunnel the long succession of trenches and steps, by which the small advanced heading was gradually widened and deepened to the full size of the finished tunnel, caused the working places to stretch back as far as a couple of miles behind the forebreast. Hence, even admitting the practicability of artificially supplying the advance heading itself with air so cold that, where the rock tempera-

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ture was from 40° to 50° C. or 100° to 120° F., the men could work a hundred yards behind the forebreast, the author considers the same means would be altogether inadequate for such a length as a couple of miles of tunnel, full of men at work and smoke from blasting. Moreover, in the usual plan of driving the advance heading along the crown of the tunnel, the water issuing from the forebreast has to flow all along the heading, and then down along all the following steps and trenches of the successive enlargements, before reaching the completed culvert in the finished portion of the tunnel. The author therefore suggests the desirability of proceeding by an inverted method, somewhat as in metalliferous mines: driving the advanced heading along the very bottom of the tunnel, and carrying the culvert forwards promptly with it, so that all water should drain at once into a narrow channel, presenting small surface for evaporation. Less moisture would thereby be imparted to the air, even when driving through very wet rock, than is evolved in drier rock, from the vast extent of wet surface exposed by the puddles and mud that are inevitable with the ordinary mode of driving. Such an inverted method would doubtless present difficulties in regard to ventilation; but more attention might advantageously be paid in tunneling to the improvements that have already been realised in mine ventilation by the adoption of systematic arrangements. For long tunnels that will take years to execute, instead of improvising foul-air outlets temporarily and at random, or opening cocks here and there on the compressed-air main, a regular system of ventilation should be carried out by means of brattices, air-doors and trunks, and should be pushed forward continuously to follow up the progress of the work. A further suggestion for facilitating the execution of tunnels through hot rock is to complete each end to the full size as far in from the mouth as can be done without the heat becoming too oppressive, say up to 30° C. or 86° F.; and then to push forward and complete the advance heading alone, without continuing the work of enlarging behind it. The practical difficulty would then be reduced to the efficient ventilation of the heading for a length of 100 yards back from the forebreast. As soon as the two headings met, a good current could be established right through from one end of the tunnel to the other, which would be largely efficacious in keeping down the temperature at the working places, during the subsequent enlargement of the central length.

Haulage.—Manual or animal labor in the working places should as far as possible be replaced by mechanical power; though how to manage this practically for the most fatiguing portion of the work—the clearing away of the spoil—yet remains to be found out. Endless-rope hauling, as already carried out at collieries, would be more convenient for removing the stuff than the use of compressed-air locomotives, the size of which prevents their penetrating so far into the advancing end, and also interferes more with the ventilation.

Artificial Cooling.—This is the most difficult question of all, and is by no means solved by the use of extensive appliances for supplying compressed air. The heat from the rock is practically inexhaustible; and, whether all the air-cocks at the forebreast are open, or all shut, the air temperature 200 yards back is practically constant and equal to that of the rock, and thenceforth gradually rises as the air travels further back along the working places. The utmost cooling at the forebreast, while four rock-drills are working together and discharging their exhaust air at 2½ to 4 atmospheres pressure, does not exceed 4° C. or 7° F. at most, the average being only 1° C. or 2° F. below the rock temperature; and during the clearing away of the spoil the air may rise as high as 4° C. or 7° F. above the rock temperature, the average being 1½° C. or 3° F. above. A table is given of periodical observations made by the author at both ends of the St. Gothard tunnel while the drivage was suspended for surveying the line of driving, the working places being then deserted and the air cocks left open. These records show that with a rock temperature of 47° C. or 116° F. it would be no easy matter to keep the air down to 35° C. or 95° F. in the working places while work was being carried on. There is no great difficulty in delivering highly compressed air in large quantities at the forebreast; the difficulty lies in arranging its distri-

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bution. Men cannot work within a distance of 5 or 6 yards in front of an aperture not more than 4 inches diameter; and often put a basket over it to break the blast. The most serious obstacle to the use of compressed air, as the sole means of cooling, lies in the low specific heat of air, whereby vast volumes become heated immediately to the temperature of the rock, without perceptibly cooling the rock itself. A jet of cold water has very little cooling effect on the air, and the mist thereby produced is decidedly objectionable; on the contrary, indeed, the compressed air should itself be supplied as dry as possible. To cool the air before delivering it into the tunnel is of little use, because its cooling effect depends much more on its sudden expansion; and also because, however cold it may have been at the tunnel mouth, by the time it reaches the inner end of a very long main, the air is found to have acquired within 2° to 3° C. or 4° to 5° F. as high a temperature as the surrounding atmosphere in the tunnel. As a means of cooling in combination with other plans, the adoption of compressed air points to the use of compressing apparatus on a much larger scale than that at either Mont Cenis or St. Gothard. A further problem will be to devise better methods for drying the air. The air reservoirs at Mont Cenis and St. Gothard answered the purpose to a certain extent, and were supplemented by additional appliances at St. Gothard. For completely drying the air, Professor Dubois-Reymond's suggestion to employ quicklime might be adopted; and the author points out that this mode of drying would be more efficaciously applied to the compressed air before its delivery into the tunnel, than by conveying the lime itself to the working places. The cooling mixture of ice and salt should, however, be conveyed in the spoil-wagons to the working places, and there discharged on the off side; as it gradually melted away, the water would run off, but without imparting so much moisture to the air as if there were no salt mixed with it. The combination of these two plans appears to the author to offer the best means of enabling tunnels to be driven at high temperatures.

Workmen and Shifts.—Italians, used to a warm climate, and taking to mining with skill and perseverance, form as valuable a class of workmen for European tunnels as the Indians of Mexico or South America for tunneling operations in those countries. Under such circumstances as obtained in the St. Gothard tunnel, the author considers that, having regard both to economy and to health, the average duration of shift should not exceed eight hours. Two hours must be allowed for walking in to the working places, when at a distance of 4 to 4½ miles in from the mouth; then some rest is needed before commencing work; and two to three hours' work is all that can be managed before starting on the two hours' return journey, which should also be made leisurely on foot. The men at the boring machines, and those clearing away spoil just behind, having the coolest and driest air, often remained fourteen hours in the St. Gothard tunnel. The men should strip themselves of clothing as far as possible, so long as the air temperature is lower than that of the body; if ever tunneling came to be done at a higher temperature, it would of course be desirable to work with clothes on. Wherever artificial cooling of the air is required, the working places should also be followed up closely by suitable refuges or chambers, fresh and well ventilated, and even filled with dry air at a slight excess of pressure, where any one overcome with exhaustion can be promptly restored, and where the men can dry and change before leaving work. Cooling beverages are recommended, for avoiding the danger of drinking too much cold water while at work.

In conclusion the author points out that, from the nature of the work in long tunnels under high mountains and through hot rock, the question of cost, and even of time, may often become a consideration of secondary importance.

HEIGHT OF WAVES.—From the result of ten thousand observations, it appears that the cubes of the heights are proportional to the squares of the velocities of the winds. A wave of 2.20 meters in height corresponds, according to the author, with a wind of 5 meters per second velocity; and as the relation $(2.20^{m})^{3}=x\,(5)^{2}$, $\therefore\ x=0.426$, and consequently $(2\,H)^{3}=0.426\,v^{2}$. Hence 2 H, the total height of the wave, $=0.75\,v^{\frac{2}{3}}$.

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AN ADAPTATION OF BESSEMER PLANT TO THE BASIC PROCESS.

By A. L. HOLLEY, Memb. Inst. C.E., &c.

From Papers of the American Society of Mechanical Engineers.

The maintenance of refractory linings in Bessemer converters, in such a way as to promote regular and maximum production, has been the subject of more experimenting than any other feature of the Bessemer system, and it is still the least perfect and satisfactory feature, excepting perhaps the casting of steel. Linings are not only eroded by the mechanical action of the charge, but they are chemically decomposed by its various slags. The silica linings usually employed have, indeed, been so improved, that an average of say 60 charges per 24 hours can be got out of a pair of converters, and the shifting of interchangeable converter bottoms (containing the tuyeres) is so rapid that it does not delay production; but the repairing of the fixed lining just above the tuyeres, where both mechanical and chemical action are most severe, is frequently the cause of delay, and the operation rapidly performed between heats is tedious and costly. The accumulations of slag on other parts of the lining must also be quarried out, else the converter will become too small for the charge.

These are the conditions of maintaining silica linings; but the difficulties are increased, probably about threefold, when the linings are made of lime, for the basic process. The basic process consists in removing phosphorus from the iron under treatment, by retaining the phosphorus oxidized by the blast, in a basic slag formed of say 20 per cent. of lime added to the charge. An acid (silica) lining would vitiate the basic slag, and would also be rapidly destroyed by it. Lime containing some magnesia, and produced by burning magnesian limestone (dolomite), is at present the only basic material successfully used for converter linings. It is usually made into bricks, which are hard-burned and built up with mortar of similar material to form the lining.

Basic bottoms and tuyeres stand ten to fifteen charges, nearly equaling acid bottoms, and they may be readily changed; but basic linings, near the tuyeres, and also in other parts where abrasion is severe, wear rapidly and must be frequently repaired by cooling the converter and inserting new bricks, or patching in some suitable manner. The converter is thus put out of use for at least twenty-four hours—a very serious delay to production. From a wide observation the author feels safe in saying that a basic lining is rarely run above 60 charges without extensive repairs, and in some works repairs are made every time a bottom is set. With some irons there is also an accumulation of slag around the mouth of the converter; its removal sometimes also causes delay.

The output of a pair of converters in Europe averages about half that of a pair of converters of the same size in the United States, and is often less than half. The limited endurance of basic linings in Europe is therefore a less conspicuous defect than it is here, where one converter must make 25 or 30 charges in 24 hours, so that the repairs of basic linings, as at present conducted, would keep an American plant idle about half the time. This delay is really as important in Europe as it is here; the greater the output from a given plant, the cheaper the product.* In order, therefore, that the basic process may come into extensive use, basic linings must be so maintained that their output will nearly equal that of acid linings.

There are two reasonable conditions of improvement; the one is to prolong the endurance of basic materials, so that their repairs can be made with little de-

* The statement sometimes made in England that the rapid production in America impairs quality of product, is but a cover for inadequate plant. Steel is obviously no better because five hours instead of one are consumed in setting a vessel bottom, or because it may take twice as long in an English works to handle materials and product.

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lay, while the converter is in position for use. There seems to be little or no progress, or probability of immediate progress in this direction. The other is the rapid and complete removal of a worn lining and the replacement of a repaired one. A third system, seriously proposed, is to double or treble the entire converting plant. The only practicable way to replace a refractory lining (which cannot be handled by itself) is to replace the vessel which contains it. The worn portions of the lining may thus be repaired at leisure, in another part of the works, rather than in position for use, where repairs would retard output.

An obvious way to replace an entire converter lining is to replace the entire converter. This system is already under construction in Europe. The method is also obvious—lifting the converter bodily out of its pillow-blocks, and conveying it to the repair shed by means of an overhead traveler; then setting a repaired converter in place by the same means. Such a plant is doubtless cheaper than a duplicate plant, and its output should be materially greater than that of fixed converters. But the operation of changing an entire converter must be slow and tedious. When the arrangement is such that pillow-block caps are required, these must be loosened by unscrewing heavy nuts; then they must be made fast to the crane chain, lifted, traversed, and set down. The blast pipe connection must be broken, and possibly some platforms must be removed. Then the traveler is placed exactly centrally over the converter, ponderous chains are made fast, the mass is raised high enough to clear surrounding parts, and drawn laterally to the repair shed; then the converter is placed centrally over its seat and lowered and steadied (as it swings from a chain) into its pillow-blocks. The repaired converter is raised, traversed, and set in place by repeating all these operations; the blast connexion is then made, and the pillow-block caps are lifted, traversed, steadied into place, and screwed down. If the converter is removed in sections, transferring each section and making the refractory joints will occupy much more time. The chimneys and the openings in the side of the building must be high enough to make passage not only for the traveler but for the converter when lifted out of its seat, and for the chains that sustain it. A traveler of the required power, height, and length is obviously a ponderous and costly structure, and in work with reasonable speed it must have independent steam power—the hydraulic system of the works cannot well reach it.

The method of replacing the lining proposed by the author and shown in the engravings is *removing only the shell* of the converter, lowering it out of the trunnion ring easily and rapidly, by means of a simple lift and car, and replacing a repaired shell by the same means. No pillow-block caps, blast connexions, nor other surrounding parts are touched; a dozen cotters are knocked out, the shell is lowered and run straight back to the repair shed, the new shell is run in, lifted, and cottered on; this is all, The machinery and transference are on the general level, and not 40 ft. or more up in the air. The car may be moved by a small reversing engine or by a hydraulic capstan, by means of a wire rope and sheaves suitably arranged. The car runs against a stop, and the lift is perfectly vertical, so that the shell may be put in place by two rapid motions without the delay of adjustment.

The lining may be heated before the shell is put in place, and bottoms (and tuyeres) may be separately removed, as at present, or they may be taken away with the shell and repaired without removal from it. In the latter case, the shell must be placed in trunnions, in the repair shed, so that the bottom may be turned downward for repairs. But if the bottom is first removed, the shell need not be placed in trunnions in the repair shed; the shell will stand mouth downward on the car, a position most favorable for repairing both the mouth and the lining about the tuyeres, which are the two places chiefly needing repairs. This is doubtless the better plan, and it saves the cost of supplementary trunnion rings and turning gear. The diagrams show the converter hung so high above the general level that the bottom and tuyere box can be hauled out, with the shell, under the trunnion ring. In case the bottom is previously removed, the converter may be hung some 3 ft. lower.

It has been remarked that in American works converter bottoms are changed so

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rapidly that one is always ready, even when tuyeres stand but eight or ten operations. Changing converter shells is much more rapid than changing bottoms. The several operations of removal and transportation are the same, but the converter lining must be trimmed out to receive the new bottom, and a refractory joint must be made. The new shell has merely to be cottered on.

The comparative cheapness of apparatus to change the shell, instead of the entire converter, is obvious. The two hydraulic lifts for removing the bottoms are made heavier, and there are several cars of simple construction; this is the entire extra apparatus. The increased cost of the converters is not important. In the other case the traveler, with its engine and the standards and turning gear in the repair shed, and the trunnion rings and pinions (the chief cost of the converters) for each spare shell approach in expense that of a duplicate plant complete.

But one objection has been raised, as far as the author is aware, to the plan proposed, and that is the possibility of damage to the lift under the converter, in case the charge should burn through and fall upon it. To avoid such damage, the lift table may be sunk several inches below the pit level and covered with sand. It may be remarked that lifts under converters are used in nearly all the American works with satisfactory results.

The engravings illustrate the construction and arrangement so fully that little explanation is required. The trunnion ring is of cast iron with an inch wrought iron lining; or it may better be a steel casting, which will not require a lining. There is a 2-inch annular space between the trunnion ring and the converter shell, and the shell is prevented from shifting laterally by means of the wedges. The car is raised by the lift to receive the shell; or the shell may be lowered by means of a fork on the lift passing through the car.

This construction of converters has led the way to a general improvement in the design of the plant. The shells and bottoms may be run out laterally into the converting house, but the space here is insufficient for convenient repairs, and the shells for one converter could not be well got to the other. In order that there may be one common place for repairs, and ample room both for spare shells and spare bottoms, they must be run out in rear of the converters. If blast furnace metal is brought directly to the converters, this rear space is not otherwise wanted; but if cupolas are placed there, as is usually the case, they must be so arranged that the shells can pass out under them.

But the cupolas (excepting the spiegel cupolas) may best be placed elsewhere; if there are blast furnaces, the cupolas may be so arranged near them, as to utilize the same system of transportation, hoisting, blowing, and hot blast. There should be plenty of spare gas from good furnaces to heat cupola blast. These are very important considerations, regarding both cost of plant and economy of working. And judging from the experience at many works, the disadvantages of hauling fluid iron some thousands of feet in a railway ladle, are less than those due to crowding the melting department and its stock yard and appurtenances, close behind the converters. Fluid iron is hauled from one to two miles * without chilling: it need usually be hauled but a few hundred feet; and the cost of the transporting plant and service should be about the same for the two systems. There are two important advantages in the arrangement.

1. Placing only the spiegel cupolas, instead of the entire melting department, close behind the converting house, leaves its rear comparatively open to free ventilation, thus cooling not only the space around the converters, but also the casting pit.

2. This arrangement provides ample room for the convenient removal of slag, which in the basic process is very voluminous; one long dumping car placed under both the converter and the ladle catches it all, and as the bottom of the pit is on the general level, the slag is neither handled nor lifted—the car is simply hauled out by the yard locomotive and dumped. Experts well know the cost and inconvenience of breaking up and quenching slag in the pit, and of lifting it out of the pit and then loading and removing it.

Iron may be got to the converters in

* At the Barrow Works it is hauled two miles, at Ebbw Vale some five miles.

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a ladle by various means. It may be hauled on the general level, to one or more hoists, and run into short spouts or directly into the converter mouths, or it may be drawn up a gradual incline, or lifted by a hoist to an elevated railway near the converters, and thence tipped or tapped into them directly or through spouts. The short elevated railway has one conspicuous advantage—it is out of the way of all other apparatus and operations; it does not cross railways, nor interfere with any transportation on the general level. This is an important feature when a charge is made every 20 to 30 minutes. The ladle may be run to the converter mouth * by various means, so as to tip directly into it, but the application of power to the transportation is awkward and difficult, so that there is more or less delay. The ladle is drawn by a locomotive to short, steep spouts leading to the converters; there is no lateral nor hand movement, and hence no delay. A spout leads to each converter, chiefly for the purpose of leaving the space between the converters (where the common spout is usually placed) quite free for the spiegel ladle.

The spiegel cupolas and their appurtenances occupy so little room that they are placed, without interference with other apparatus, very near and above the converters. A railway ladle receives the spiegel from either cupola and tips it directly into the converter quickly, and hence completely, by a short run and without hoisting or lateral movement. It may be weighed in transit if desired. The wide platform between the converters is at other times free for bringing lime, scrap, or other materials to the converter mouths, and these materials are conveniently raised by the cupola hoist.

The floor of the converting house is raised a few feet, so that the pit bottom may be on the general level, for the convenient removal of slag, as before explained. The ground outside of the converting house slopes gradually to the general level; this facilitates the removal of products, and also the drainage.

The plant for repairing shells consists of two turntables, some short railways, and a shed, also some platforms, and a lift for materials. If bottoms are to be removed with the shells, there must also be mounted trunnion rings and turning gear, also a crane, in the shed; but, as before explained, this seems unnecessary. Room is shown for repairing four shells at a time, but the railways may be lengthened to accommodate more. The plant for repairing bottoms consists of short railways and turn-tables, a space for ramming bottoms under a shed, and the necessary ovens for drying them; also a crane which sets the bottoms directly on the oven cars. If tuyeres of ordinary size are used, fewer ovens are required; if the bottom is all one tuyere, rammed around rods, it must be burned for two or three days, so that more and hotter ovens are necessary. The repairing department may obviously be arranged in other ways, to suit special cases.

The average output of the American plant, having two 6-ton to 7-ton silica-lined converters in one pit, is 100,000 tons of ingots per year. It will doubtless appear that the plant under consideration should produce more with basic linings, because it has 10-ton converters, and means of keeping one of them in constant repair, so that the converting operations may fellow one another without interruption.

Recapitulation.—1. The endurance of basic linings is so small that the ordinary system of repairs would reduce the output of an American plant about one-half.

2. The only adequate system of repairs, with existing basic refractory materials, is to remove and replace linings bodily by removing and replacing the vessels containing them.

3. Changing converters, trunnions and all, requires very costly apparatus, and much labor and time in disconnecting parts, and in making the transference.

4. Changing only the shells of converters (leaving the trunnions and their connexions undisturbed) requires only cheap and simple apparatus; and the operation may be performed so quickly that basic linings will give the maximum output of acid linings.

5. Leaving the building open in rear of the converters, instead of placing the melting department there, gives good ventilation and ample space for bottoms and shells to be run out for repairs, and for slag to be removed from the pit. The cupolas (excepting the spiegel cupolas) may be placed elsewhere, especially

* As at the works of Bolckow, Vaughan & Co.

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by adjacent blast furnaces: and melted metal may be transported thousands of feet without difficulty.

6. Placing the pit bottom on the general level allows slag to be hauled away directly, without rehandling or lifting. The elevation of the converting house floor, thus produced, facilitates the removal of products.

7. The metal ladles are brought in behind and above the converters, and discharged by spouts, in order to avoid the delay of getting them to the converter mouths; and two spouts are used, so as to leave the space between the converters open for a short run of the spiegel ladle, and of lime and other solid materials to be charged.

8. The spiegel cupolas are placed near and above the converters, so that the metal may be run in quickly and completely, without vertical or lateral movement, by means of a ladle car.

9. The repairing plant is conveniently placed in rear of the converting house, but it may obviously be modified in extent and position to suit local circumstances.

EXPERIENCES WITH ASPHALT.

From Selected Papers of the Institution of Civil Engineers.*

II.

With reference to the objection to asphalt, on the ground of slipperiness, the remedy was to be found in good scavenging. Mr. Delano had received a letter from the manager of the omnibus company in Paris (a company possessing twelve thousand horses and a large number of vehicles) recommending the Charlier system of shoeing, which was well known in England amongst veterinary surgeons and road makers. If asphalt could be employed in the courts and narrow roadways of large cities, where so many poor children were poisoned by the vitiated air and filth, he believed the result would be very advantageous. He hoped that analyses would be made of the air over asphalt roadways as compared with roadways laid with sets. The scavenging in London was very bad, and a person coming to the metropolis, after an absence of some years, could not help noticing it. He was surprised to see the roadway in front of Buckingham Palace in a vile condition. Of course, as asphalt was impermeable, it had to be cleansed, there being no deodorizing principle in it, as partially existed in macadam, before saturation. It would be observed that no remarks had been made as to the comparative cost of asphalt and macadam. In Paris it was rather difficult to get the information, but he had ascertained that the cost price of macadam, including steam rolling, was 6 francs 30 centimes per square meter. The maintenance, however, of a macadamized road might reach the enormous sum of 17 francs per square meter per annum; that was the case in such places as the Champs Elysées and the Rue Royale, where there was a heavy traffic. But the cost of macadam did not end there; it formed banks in the river, and at present steam dredging was employed to remove the banks of sand in front of the drains in Paris. He had a report by M. Vauthier, civil engineer, and a member of the Municipal Council of Paris, from which it appeared that the maximum cost of granite was 22 francs per square meter. The mean cost of the Paris roadways, extending over 6,000,000 square meters, was 17 francs, the mean cost of their maintenance being 1 franc, not including scavenging nor interest upon outlay in any case. In narrow, crowded thoroughfares, the cost of maintenance was, he believed, 3½ or 4 francs. The chairman of the Paris Cab Company stated that the traction on asphalt was much less than on any other system of roadway. The manager of the Omnibus Company corroborated this opinion, and considered that the wear and tear of carriages, horses, harness, &c., was much less on asphalt roads than on any other. With regard to the

* Abstract of the Discussion following a Paper on Asphalt, by Mr. Delano, published in Van Nostrand's Magazine for December, 1880.

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Seyssel and Val de Travers mines, of which drawings had been sent, he might mention that they contained marine shells and shark's teeth, as well as fresh water shells.

Mr. E. B. Ellice-Clark had, a short time ago, taken a good deal of trouble to ascertain the cost of different kinds of paving. He had taken Mr. Deacon's figures for the wood paving in Liverpool, believing that they were the only reliable figures ever published, and reduced them with the other calculations to the standard of 100,000 tons per annum per yard of width, with the result shown in the following table:

—	Original cost per square yard.	Annual Outlay.					
		Interest.	Sinking Fund 3 per cent. compound interest.	Maintenance.	Scavenging.	Gravel.	Total.
	s. *d.*	*d.*	*d.*	*s.* *d.*	*s.* *d.*	*d.*	*s.* *d.*
Wood pavement.....	15 1.5	7.5	10.1	0 1.0	0 2.7	5.0	2 2.3
Val de Travers compressed asphalt	18 0.0	9.7	..	0 3.6	0 0.4	..	1 1.7
Granite sets, 7 inches × 3 inches laid over a layer of 12 inches of cement concrete.....	17 9.0	9.6	0.5	0 1.3	0 2.5	..	1 1.9
Macadam in South of England..	4 9.0	2.1	..	3 6.0	1 0.0	..	4 8.1

Those figures showed that if the contract entered into by the Val de Travers Company in London could be maintained, their asphalt was cheaper even than granite sets. There could be little question as to the many advantages possessed by asphalt over almost all other materials for road paving. According to his experience, compressed asphalt was the best for roadways. In the City of London, he believed, thirteen or fourteen kinds of asphalt had been tried within the last nine or ten years, and only three of them remained at present in streets with heavy traffic. It was hardly necessary for English engineers to go thoroughly into the chemical part of the question, because all that information had been reduced to practice by the actual wear and tear in the City of London. There were some curious anomalies in the behavior of compressed asphalt to which he desired to refer. He had recently laid a footpath with that material, $\frac{3}{4}$ inch thick. In a short time a large number of cracks appeared, but the path had stood the effects of the last two very severe winters; and, although the cracks were unsightly, they did not appear to have injured the asphalt in the least. He believed the cracks were due, primarily, to the use of a cement not sufficiently purged; the concrete expanded in various directions, and the asphalt followed it, not being sufficiently elastic to extend over the fissures without rupture. Another peculiarity was that in humid weather there was a greater accumulation of dirt on the compressed asphalt than on the mastic. Perhaps the author could state, from his experience in Paris, the reason for that peculiarity. No particulars had been given as to the amount of mud in the streets. Mr. Ellice-Clark had compiled the following table with reference to that point:

Material.	Load of mud for area.	Traffic per annum per yard of width.
	Superficial yards	Tons.
Macadam.....	344	25,000
Granite sets...	500	50,000
Wood.....	1,666	25,000
Asphalt.....	4,000	500,000

So that, as dirt meant mud in wet weather and dust in dry weather, asphalt was unquestionably a most economical paving. One of the greatest advantages possessed by asphalt for street paving was the facility with which repairs could be executed.

Cheapside had been laid with asphalt in December 1870, and the roadway had never been blocked a single day for repairs. This alone was an advantage to a city with great street traffic, which could not be said of any other kind of

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pavement. It would be hardly possible to overrate the importance of having streets permanently open for traffic. Again the rapidity with which it was originally laid, compared favorably with other materials. In Paris, he believed, a given area of each road had to be opened in eight days; in London, fourteen days had been found ample time to take up the old stones and lay asphalt and concrete, and permit traffic. The author had suggested the use of asphalt concrete costing 80s. per cubic yard; this was too high a price, because a bituminous concrete composed of ballast, coal tar, and creosote oil, could be laid for 21s. per cubic yard, 6 inches in thickness. It had been tried in Liverpool under sets with manifest success. By using a concrete of this kind the work of laying a road could be shortened by the difference in time required for Portland cement concrete to set and that required for bituminous concrete, which was a few hours only; so that a road fit for traffic might be laid in London in eight days. There was no reason why this kind of foundation should not be equal to Portland cement concrete; and it was well worth the attention of municipal engineers and asphalt companies. With regard to foothold for horses, or rather the absence of it, the city engineer had demonstrated, by a series of observations of an exhaustive nature, that saphalt occupied a position between wood and granite, in the order named: and the popular outcry against the slipperiness of asphalt arose from the greater number of horses falling at one time. He was strongly of opinion that the author was correct when he stated that this absence of foothold was due to want of cleanliness. The city corporation had recently put down a number of hydrants all over the city area. If these were utilized in cleansing asphalt, the falls of horses would be reduced considerably The author had made no allusion to the fact that during the past few years the new pavements of Paris in asphalt were much inferior to those formerly laid. It had been asserted that this was owing to the use of the Lobsann asphalt, which did not contain sufficient calcareous matter in the natural rock.

Mr. A. SOUTHAM remarked that where it was desirable to lay asphalt on carriage ways, there could be no doubt that compressed asphalt was the best for that purpose. He had paved about 25,000 yards of footway in the parish of Clapham, since 1872. Various small specimens were first laid. Then about 1,000 yards of Barnett's asphalt, 1 inch in thickness, was tried; the cost was 4*s.* 6*d.* per square yard, and it was still in existence, and might be considered a fair path. It was afterwards thought desirable to make the best footpath that could be obtained in asphalt, and, after considerable investigation, the Val de Travers compressed asphalt was selected, and more than 20,000 superficial yards of that material had been laid. A great object was to secure uniformity of paving throughout the district, also facility in executing repairs. It was somewhat unfortunate that transverse cracks had appeared about every 6 or 8 yards. They made their appearance from about three weeks to twelve months after the path was laid. Some of the cracks were cut out, when it was found that corresponding cracks existed in the concrete below. The whole piece was cut out, and new concrete put down, which was kept exposed for six or eight days to harden. Then a thin coating of mastic asphalt was laid over it, previous to the powder being restored. Similar cracks, however, appeared again in the same line, and it was difficult to account for them. He thought to some extent they depended upon the concrete. Great pains were now taken with it, and 6 parts of ballast to one part of cement had been substituted for 8 parts of the former to 1 part of the latter, clean Thames ballast being used; it was mixed with very little water, and was well beaten with shovels. The cement had been tested, and had broken at a pressure of 450 lbs. to the square inch after seven days, during six of which it was laid in water. The concrete for the last piece of paving was kept open for fourteen days, so that it was dry before the powder was laid upon it; the footpath was previously rolled and consolidated; and this path had shown very few cracks. He was inclined to think that compressed asphalt was scarcely so durable as had been generally supposed. The mastic asphalt he believed was somewhat harder, though it was objectionable from

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the uncertainty of its mixture, from the difficulty of making the repairs to match the rest of the paving, and from the furnaces for melting it having to be in the street. He had not yet decided whether it was advisable to continue the use of compressed asphalt, or to resort to the mastic. He was surprised at the immense area of footway paving laid in Paris, but the author had not stated of what it was composed. Mr. Southam presumed that was chiefly mastic. The Val de Travers Company had assisted him greatly by their willingness to lay the concrete in any way that might be desired, and to keep it exposed for any length of time. Their manager had suggested that lime concrete would prevent the cracking, and accordingly one line of path had been laid with it. It was not a success; there were no transverse cracks, but it had failed from the settlement of the concrete, which was not yet hard, and had cracked longitudinally from the frost. The concrete in this instance was laid from fourteen to eighteen days before being covered with asphalt. Very few cracks had appeared in the city paths. The foundations were, perhaps, more solid, and owing to the greater traffic brought to bear upon them, the asphalt was more compressed and kept in its place. The asphalt in Clapham had suffered from cracks during the late severe winter, but they had all been longitudinal instead of transverse, and after the frost they had closed and did not look so bad. In this district the use of asphalt would probably be largely extended if a perfect paving could be laid. He would be glad to know which was the best description of asphalt to use for footway paving.

Mr. H. C. Scott observed that, as a director of the Val de Travers Asphalt Company, he might be permitted to refer to their experience of London roadways. The question of cracks upon compressed asphalt footways was one that he frankly confessed had once given them some concern; but they were of opinion that the fault would only last a short time. In going along the Cheapside pathway, which had been laid between three and four years, he had not observed any cracks; and in Moorgate Street, where it had been laid four or five years, there were very few. He had not discovered that the pavement was affected by the humidity of the atmosphere or by rainy weather. They sometimes found, when the drying process had set in, that there was a little streak through the footway, but in a day or two it entirely disappeared. On the grounds of economy, noislessness, and cleanliness, after the many pamphlets that had been written and the many reports presented, there could be no doubt as to the superiority of asphalt; and he believed that compressed asphalt for roadways possessed greater advantages than any other material. The roadway in Cheapside had been laid ten years, and it was still in existence. The heaviest traffic in the world passed over it, but it had never been interrupted for an hour. The repairs were done early in the morning, and the result was that Cheapside possessed a clean, noiseless, and cheap roadway, which, as he knew from the shopkeepers, was regarded as an enormous boon. As to the objection on the grounds of slipperiness, that, as the author had explained, was a question of cleansing, and not a question of asphalt. If engineers and district surveyors would impress upon the Vestries of London the importance of spending more money in cleansing the roadways, they would confer an immense benefit upon the community. The condition of the lanes, slums, and alleys of London was deplorable. The rejected granite sets and York flagging from the richer districts were transported to those localities, where the children of the poor were congregated, and where they played about all day in puddles. If the authorities would only give them asphalt, they would be doing something towards making life tolerable to many who now regarded it as little better than a burden.

Mr. W. B. Lewis asked if any one accustomed to lay asphalt upon concrete had ever tried the plan of laying the concrete in slabs, with joints, in order to prevent cracks. Engineers who had used concrete in large masses were aware that the difficulty of cracks frequently occurred. At the Victoria docks, in one wall 1¼ mile long, and 33 feet or 34 feet high, of solid concrete, there was a hair crack through it at about every 14 feet. He presumed that this arose from the material being homogeneous, and that

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there must be expansion and contraction somewhere. Possibly the cracks in the asphalt pavement arose from the concrete being laid in one continuous mass.

It must have yielded somewhere to atmospheric influences, and consequently cracked. If it were laid in slabs, with joints ever so small at intervals, possibly that would get rid of cracks in the asphalt.

Mr. John Knight said that Portland cement concrete expanded and contracted according to the weather, while asphalt, if laid in a mastic state, neither expanded nor contracted, whether ½ inch or 1 inch in thickness. It appeared that the asphalt in Brighton had not cracked because it was in an elastic state, while that laid in Hove in a compressed state had cracked. The reason for the cracking was that it was not of sufficient thickness—only ¾ inch; and the same reason applied to other cases that had been mentioned. No cracks had appeared in Cheapside or in Moorgate Street, because the asphalt had been laid of sufficient thickness—1 inch. Compressed asphalt should not be laid less than that thickness, otherwise it would crack in every direction. The first asphalt of the Val de Travers Company that he had noticed was in a mastic state. It did not last very long; it was not suitable as a mastic asphalt, but as compressed asphalt it was very good. When a surveyor saw a piece of York stone, he could express an opinion as to whether it was good or bad; but he could pass no such opinion with regard to asphalt, whether in a mastic state or compressed. The goodness of the material was only to be ascertained by its durability. The best piece of asphalt in the city was laid in a mastic state in King William Street, eight or nine years ago, and it still existed as when first laid, with the exception of a few repairs for gas and water purposes.

Mr. J. Fogerty observed that he had had some years' experience, both as an architect and as an engineer, in laying pavements and in the use of asphalt and Portland Cement for the covering of roofs and other structures. He did not believe that a layer of ¾ inch of asphalt of any kind was sufficient, especially in footways. The chief cause of cracks was, he thought, to be found in the concrete, and there was only one way to get rid of them—a plan that he adopted ten years ago—never to lay more than nine feet length of concrete at once, bringing straight joints across the footpaths by inserting boards, withdrawing them when the concrete was soft, and leaving the fissures open for a considerable period. The great trouble in getting concrete laid was, to induce the workmen not to use too much water. It could not be laid too dry, especially where it had to be covered with Portland cement or asphalt. A long discussion had recently taken place at the Royal Institute of British Architects on Portland cement and concrete, and it seemed to be the general opinion that one of the chief troubles connected with concrete was the over use of water by workmen. If it was laid almost dry, and thoroughly rammed and jointed at intervals, the joints being left open until the water had evaporated, it might be covered with asphalt without any fear of cracks, provided there was a solid substratum. But where it was laid upon clay difficulties would invariably arise, unless there was interposed between the concrete and the clay a considerable amount of hard, pounded, dry filling for drainage purposes. The most difficult pavements were those laid upon a clay substratum, and he knew of no mode of curing the difficulty except by getting out a considerable depth of clay, and replacing it by dry material. For covering roofs, arches, and the like, he preferred the mastic to the compressed asphalt. For level roadways and footpaths there could be nothing better than the compressed asphalt for pavements, on the ground of cleanliness, but the danger of horses slipping in greasy weather was a serious one. He had often passed through Cheapside in muggy weather and seen several horses down at one time. Whether that could be obviated the did not know. The question had not been fully dealt with in the paper, and he hoped the author would allude to it in his reply. The only remedy that could be suggested was a thorough cleansing, which, so far as Cheapside and similar streets were concerned, could only be done during the hours of traffic by means of numerous hydrants, and the constant use of hose-pipes with large

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side apertures, such as those used in Paris, to carry off the washings into drains or reservoirs. Allusion had been made to the operations of gas and water companies which destroyed the roads and pavements in cities. Some twenty years ago, the parish of Marylebone offered a prize for the best section of subway, and it was won by a young student in the engineering class of University College—Mr. Davis. Since that time very few subways had been constructed in London, and even in those, gas and water companies were very unwilling to place their pipes. The only objection he had heard was that the escape of gas in such enclosed places would be dangerous. On that point he should be glad to hear the experience of the city surveyors who had charge of streets and subways in which gas pipes were laid.

Mr. HENRY GLENN attributed the cracks that had occurred in the Val de Travers asphalt to the want of a sufficient quantity of bitumen. Heating the powder drove off the bitumen to a large extent, and if the quantity was reduced, as stated in the paper, to 9½ or 10 per cent., cracks would be sure to occur in severe weather. In the case of mastic asphalt, the difficulty could be obviated, because the cauldron was in the street; and if the asphalt did not contain a sufficient quantity of bitumen, an addition could be easily made to it, and an experienced foreman would know what quantity to add. Some reference had been made to mastic asphalt not wearing so well as other kinds of asphalt. A good deal depended upon the size and quantity of the grit put into it. There ought not to be too much, and the size should not be too large. If it was too large, it would work out, which a small piece of grit would not do. When the Barnett Asphalt Company was in existence, it was the practice to use the large grit, and the consequence was that nearly all their work failed. He had seen concrete laid down in 6 or 7-feet lengths, and allowed to get thoroughly dry at the end; and when the next layer of concrete was put on, it had not been sufficiently wetted and properly jointed. In such a case cracks would arise through the concrete; and if the asphalt did not contain a sufficient quantity of bitumen, it would go through to the surface of the asphalt. He did not agree with those who had said that the concrete should not be laid in long lengths. He thought the more men that were employed, the more quickly the concrete could be laid, and the longer the lengths the better. The work was then all of a piece, and was in the best condition to receive the asphalt.

Mr. E. J. HARRISON had under his control, on behalf of the Val de Travers Company, the majority of the asphalt roadways in the City of London. The history of the compressed roadways in London was soon told. The first laid was that in Threadneedle Street in 1869. It consisted of a layer of two inches of Val de Travers compressed asphalt on a concrete foundation. He had no doubt that many members had noticed it when it was being laid, as it created a great sensation at the time. He remembered looking at it and wondering how many weeks it would last. It was now within two months of being eleven years old, and was still, as it always had been, in good condition. Some new Aberdeen granite had been laid beside it for a trial of endurance, and seven years afterwards it had got into such a state as to require re-dressing and re-setting; but that was not done, because, when the inhabitants of the street learned that the street was going to be closed for repaving, they expressed a preference for an asphalt roadway, which the city authorities gave them. Since 1869 the progress of asphalt roadways throughout London, though rather slow, had been steady. There were now in the city of London alone 12,000 or 14,000 thousand lineal yards of paving, covering a superficial area of 150,000 yards. The Val de Travers Company had upwards of one hundred roads under their charge, many of them being the main thoroughfares of the city, having a concentrated and heavy traffic; and the area would be considerably increased during the present year. One noticeable feature with regard to the use of asphalt was the great number of preparations that had been tried. Between 1870 and 1880 more than fifteen had been employed in London, most of which had proved failures. His Company had already replaced eight or ten of them, not always under favorable cir-

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cumstances for the company. In order to shorten as much as possible the time during which the streets were closed for re-paving, the company had generally agreed to lay its asphalt upon the old concrete foundations, some of which had been almost as bad as the asphalt that had been placed upon them, while others had been damaged by the traffic passing over them after the asphalt had worn out. In main thoroughfares like those of London, where every hour's stoppage of the traffic affected not only the occupiers of the particular street, but more or less remotely the traffic of the whole of London, the use of a paving material which required constant renewals or freqnent repairs was a serious matter. He certainly could claim on behalf of the Val de Travers Company, that it had never closed a city street for repairs, and such repairs as it had done had never affected the traffic in any appreciable degree. A very little hole, if neglected, speedily became a big hole, and for their own interest, if for no other reason, they had always taken care of the little holes; the repairs, therefore, had been generally done on a small area, rarely exceeding 2 or 3 square yards, and early in the morning before the traffic commenced. The openings for gas and cuttings for water pipes, which were generally a source of great obstruction, were less serious with an asphalt road than with any other paving material. A hole could be cut exactly the size required, and when the work was done it might be made good immediately. Moreover, leakages in mains under an asphalt road were less frequent than under any other material, on account of the absence of vibration. Still those cuttings had to be made, and frequently there was a trifling settlement of the new work, producing hollows and forming puddles, which were more conspicuous on an asphalt surface than on any other; so that he should be glad to see the introduction of subways under the London streets. At the request of the author, he had had small samples of the roadways cut out from some of the oldest roadways having the heaviest traffic, and they were on the table for inspection. Two of them were from Cheapside, ten years old; one was from old Broad Street, and another from Gracechurch Street, nine years old; and one was from the Poultry, a re-lay which was only three years old. The roadway of the Poultry was only three years old, because the houses on the north side were set back several feet three years ago, necessitating an alteration in the footway and roadway. The company laid down new concrete where necessary, and faced up the old, and then spread asphalt on the top of it. They had good weather, and with the assistance of the authorities, and the good will of all the inhabitants, they managed to carry out the work in seventeen days. It had proved very satisfactory, and they had never had occasion since to spend a penny upon it. When Mr. Deacon's Paper on "Street Carriageway Pavements" was read and discussed,* very little was said about asphalt roadways, Mr. Deacon stating that he had had no experience of them; the gradients in Liverpool not allowing the use of asphalt. He had been struck with the unanimity with which every speaker on that occasion urged the necessity of a solid foundation for a good road. Asphalters were especially of that opinion. An asphalt road was in reality a concrete road with a surface of asphalt put upon it to carry out certain ends. If the concrete foundation were taken away, or tampered with, or negligently laid, asphalt itself would form a very sorry paving. In dealing with that question, one important point to be considered was the obligation under which the engineer or surveyor was placed to have the road closed for paving for the shortest possible time. For that reason his company had always urged the desirability of laying a concrete composed of a quick-setting Portland cement with the best obtainable ballast. As far as his experience went, if a lime concrete was sealed up hermetically by asphalt on the top, there was no knowing what might happen underneath; whereas, if Portland cement concrete were left open for a few days and then covered with asphalt, engineers could form a pretty good idea of what would happen. In London they were indebted to the French asphalters for all that they had first learned as to the nature and treatment of asphalt; but he thought that they had now beaten their instructors, putting down better

* *Vide* Minutes of Proceedings Inst. C. E., vol. lviii., p. 1.

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work and maintaining it better. He had been struck on a recent visit to Paris, with the condition in which some of the roads had been allowed to get. He believed that it had partly arisen from the system there adopted of requiring the contractor to take up every year, whether it was required or not, one-fifteenth of the work laid down, which he regarded as a premium on bad work. Another reason was the use of lime concrete with lime mortar on the top. The only failure that he knew in Val de Travers roadways had been in connection with the use of lime concrete under lime mortar in the roadway laid (after that in Threadneedle Street) in Holborn, opposite Gray's Inn. It had been laid by Englishmen who were novices, and who followed slavishly the specification prescribed by the French engineers. That specification prescribed a layer of about 9 inches of lime concrete with $\frac{3}{4}$ inch of lime mortar. When the concrete was ready to receive the asphalt, a fire broke out in Holborn, and the barriers protecting the concrete were broken down; the place was flooded with water, the engines drove over the concrete, and the population of Gray's Inn Lane trampled it down. It was subsequently made good; the asphalt was spread, and some time afterwards the Val de Travers Company succeeded by inheritance, to its maintenance, and certainly it had been a "heritage of woe." For five or six years they had kept up the road at considerable expense and trouble, and at the end of that time they received the permission of the road authorities to relay the whole in two longitudinal strips, so as not to stop the traffic. On removing the asphalt it was found that the lime concrete had never set, that the mortar floating had never adhered to the concrete, but was mostly in powder, produced either by the action of the rammers, or by the traffic afterwards. They broke up the concrete, sifted out the lime, relaid the foundation with Portland cement, and put fresh asphalt on the top. That was done about four years ago, and the work had since proved satisfactory. Some of the workmen now in his employ, who had been previously engaged in Paris, had told him, that in several of the roads there the asphalt had been laid upon the existing macadam. The author had referred to certain roadways of asphalt with granite channels. It appeared to Mr. Harrison that granite channels were superfluous. As between an asphalt roadway with a granite channel, and a granite roadway with an asphalt channel, *qua* channel asphalt would be the preferable material. The Val de Travers Company had laid a great many footpaths in England, both in mastic and in compressed asphalt, and he was of opinion that it was not desirable to have the material of a less thickness than $\frac{3}{4}$ inch. Some years ago they laid $\frac{1}{2}$-inch mastic footpaths, but the result had not been such as to encourage that mode of construction. It had even been adopted in some of the streets in the City of London having the heaviest traffic, such as Gracechurch Street and King William Street; but in four or five years the footpaths had become so much worn that it was thought desirable to take up the $2\frac{1}{2}$ inch mastic and lay down $\frac{3}{4}$-inch compressed, which had stood fairly well. He had been surprised to hear that his company had been credited with a preference for lime concretes over cement concretes for footpaths. That was far from being the case. The footpath referred to was laid as a sample under some special conditions. It was a fact, that in certain footpaths, particularly those in the suburbs, where there was little traffic, transverse hair cracks appeared from time to time. The first cracks to which his attention had been directed, were in the footway round the garden in Leicester Square, and appeared six years ago. The cracks were there to the present time; they had not in any way affected the stability of the work, but they were unsightly, and he should be glad to be able to prevent them. He had noticed that the better the concrete on which the footpaths were laid, the greater the number of cracks appearing in them, and the worse the concrete the fewer the cracks; indeed, if they laid the concrete bad enough there were no cracks at all. He had found it impossible to lay a horizontal riband of good cement concrete 3 inches thick without finding a hair crack at every 10 or 20 feet. The crack in compressed asphalt followed the crack in the concrete. Of course the footpaths were not subject to that hardening effect which was produced by the

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rolling of wheels on roadways. He never remembered seeing a crack in an asphalt roadway, although he had little doubt that cracks might be found in the concrete underneath. Mastic asphalt being more elastic than compressed asphalt, the tracks were not so numerous in it. Nevertheless he was of opinion that, *cæteris paribus*, a compressed footpath was a more desirable one than a mastic footpath. It was pleasanter to walk upon, owing to the absence of grit; it was handsomer, and it was also cheaper to lay; moreover, it had not the disagreeableness of mastic footpaths, arising from the smell of the burning asphalt in the cauldron. With regard to the surface duration, he believed that the compressed asphalt was better than the mastic. He was not surprised that very little had been said on the subject of slipperiness in connection with asphalt. The matter really lay in a nutshell. Roads when dirty were slippery, whether paved with granite or asphalt; but in the case of granite, a slipping horse might be pulled up by the joint of the second or third stone, whereas on an asphalt road there were no joints to prevent a fall. The true remedy was to keep the roads clean, as was done in Paris, where the asphalt road was a favorite one with cabmen and omnibus drivers. He was glad to find that, quite recently, the City authorities had arranged to have a certain number of hydrants used for washing the streets. He hoped that the experiment would be carried out carefully, and that the streets would be washed every morning before the traffic commenced.

Mr. H. S. COPLAND said that the paper, although its title was "On the use of Asphalt in Engineering," dealt only with one kind of asphalt, the Val de Travers, and of its use chiefly in the construction of roads, or rather in the coating of road surfaces, which was only a small branch of a large and important subject. He maintained that asphalt was wrongly used if employed as the surface of a roadway. Engineers had to consider other things besides the cleanliness of the material and its noiselessness. As to the latter, though asphalt was free from one class of noise, it was attended with another—the clatter of the horses' hoofs, which was very irritating to persons of nervous temperament. Nor was it enough to pay attention to the durability of the road; they had also to take into account the foot-hold given to horses, and the amount of tractive effort required, not only to draw the vehicles along the road, but to start them; and they had further to consider the cost of construction, maintenance, and cleansing. In regard to cleanliness, a good asphalt road was undoubtedly the best that could be constructed, and as to its impermeability to water, thus affording a protection to the foundation, it was also an excellent material; but for slipperiness and deficient foot-hold it was about the worst road in existence. As laid by the Val de Travers Company, it was exceedingly durable, but it was costly in the first instance as compared with other materials. Taking all the requirements into consideration, he had arrived at the conclusion that for the surface of a road no material was equal to wood. But in order to obtain a good foothold on wood, it was necessary to leave spaces between the courses, principally for the want of which the old wood-roads of twenty years ago had fallen into disuse. Other reasons for their discontinuance were that they had not been placed upon a proper foundation, and the blocks were not properly cemented or keyed together. He believed that the proper mode of using asphalt was to lay a damp-proof course of that material (to prevent the infiltration of water) on a foundation of concrete, and then to place wooden blocks upon the asphalt layer to take the surface wear of the traffic. The blocks were not only keyed to the concrete, but they were keyed to each other by the asphalt running into the joints, thus forming a monolithic slab of material, which afforded a good foothold, could be readily kept clean, and was comparatively noiseless. As such a slab extended from one side of the road to the other, the weight of the traffic was transmitted over a large area, and was not confined to one block; the road being elastic, would wear uniformly; it would not press too directly upon the concrete foundation, and particularly on one part of it, and a smaller depth of concrete would suffice. Such a surface, if the wood were properly selected, would remain perfect for a number of years. In

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Boulogne, four and a half years ago, he had laid down blocks only half the depth of those used in London, for a traffic exceeding 120,000 tons per annum in a street 20 feet wide. The surface was still perfect, and there were no depressions. The wear was solely from surface attrition, and had amounted to about $\frac{3}{16}$ inch per annum. The London company formed to work his English patent had laid 60,000 square yards in London roads which had not in some cases worn quite so well as the road in Boulogne, in consequence of the wood not having been so well selected. The cost of such a road, fit for the heaviest traffic in Paris, would be from 12 to 15 francs per square meter (the amount given for the road described by the author being 17 francs), and the average cost of maintenance would not exceed 1*s.* per square meter per annum. He therefore maintained that his road, while offering all the advantages of freedom from noise, and being a better road for traction, would cost the municipality of Paris less, over a term of years, than asphalt. With regard to slipperyness, it appeared from the report presented by Mr. Haywood to the City Commissioners of Sewers in 1873, that on granite pitching one horse fell for every 132 miles traveled. On Val de Travers asphalt one horse fell for every 191 miles traveled; and on wood pavement (not asphaltic wood pavement, but the nearest approach to it), one horse fell for every 446 miles traveled. But the nature of the falls ought to be taken into consideration. Of the total number of falls on wood pavement, only one-eighth might be called dangerous, while three-sevenths of those on asphalt were dangerous. The danger was not simply from broken knees and from directly observable damage done to the horse, but from sprains in the attempt to regain a foothold. Injury of that kind was far more serious, more insidious, and less easy of cure. He concluded that, in all crowded streets, asphalt as a surface pavement should be given up. He agreed with Mr. Scott, that it might be used with advantage for the paving of narrow courts, alleys, and play-grounds for children; but the safety of grown-up people ought also to be considered, who, in crossing crowded thoroughfares, were constantly run over by horses, which on asphalt roads trotted at a great speed, and were pulled up with difficulty. The durability of all roads depended to a great extent upon the character of the concrete. He found that lias lime, properly used, was as good as cement, but it was necessary that it should be ground to a fine powder, and that it should be fresh and uniformly mixed, care being taken not to use too much water.

Mr. E. A. Cowper observed that no one had touched upon the cheap method of making footpaths in the neighborhood of London, with tar and gravel, as now practised. A few years ago the material was mixed with stones and gravel, forming a sort of pudding, the whole thickness being put in at once, and as soon as the hot weather came, the tar exuded from the top, making a very bad, soft footpath. Of late years large stones alone had been put at the bottom, which, having received a coating of tar or pitch, just touched each other at points with their tarry surfaces. Above that a thin coating of finer material was placed, with a thin coat of fine stuff on the top. This made a splendid path; no tar exuded from the top, as any surplus drained down to the bottom, and the path was firm, hard, durable and clean.

Mr. J. Lovegrove desired, having had some experience in the use of asphalt on public footways, to make a few remarks. In the year 1869, when in Paris, he observed the peculiar condition of the roadway opposite the Tuileries; the asphalt appeared to have worked up into leaf-like layers, in a plastic state, and those layers occurred at distances of about 100 feet. He had little doubt that the cause was that the road had been repaired with asphalt too rich in bitumen. In the same year he also observed the paving of the road along the Rue St. Honoré; the process appeared to be different from that which was now adopted. There was first a layer, 4 inches thick, of hydraulic lime concrete, and then a layer of about 1 inch of mortar troweled. The concrete was beaten with instruments similar to the tools used by gardeners for beating turf. On the top was a 3-inch layer of powdered asphalt; the channels were pressed into form by a rammer about 9 inches long and 2 inches thick, and were well rammed; then a heated roller was applied over the whole surface. A roller with

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eight or ten carriage wheels, working upon a common axle, was also passed over it in various ways for a considerable time. Before he left Paris a considerable portion of the asphalt had to be taken up, and he believed the whole was reinstated He well remembered the care with which the concrete used in Threadneedle Street was mixed, and the quiet, steady way in which the foreigners worked upon the asphalt. It was a unique piece of work, and he would urge upon all asphalt representatives to endeavor to repeat it elsewhere. Great difficulty had been experienced in keeping in order a short piece of asphalt roadway opposite Hackney Town Hall, divided into three slips by tram lines, the tram-rail and the asphalt being too unlike to be kept together. He had recently tried a rough course of granite pitching at the side of the rails, which seemed to promise well. If well-dressed stones were laid in bond course, he thought they would answer very well. In 1872 a sample of asphalt had been laid along the footpath at Dalston Junction for a length of 550 feet, by the Val de Travers Company, and a second length was laid by the Limmer Company. The first sample near Dalston Junction, being subjected to the greater wear, was renewed eighteen months ago; the other length was now wearing near the fence line, the concrete being exposed in patches. In 1874, a layer of $\frac{3}{4}$ inch of compressed asphalt was put along the busy part of Kingsland, and a path was also laid in a quiet street in Stoke Newington. Shortly after cracks appeared at intervals of about every 12 feet, which he attributed to the contraction of the material during cooling. He did not believe that the concrete was affected. He had that day gone over a portion of the work and tested one of the cracks, and found the concrete quite sound. He had placed upon the table rubbings of three worn-out places; they looked more like a representation of the craters of the moon than a worn-out asphalt path, but it was an interesting mode of showing the condition of the footpath. Since 1876 about 160,000 superficial yards of gritted mastic asphalt had been laid in Hackney;* it was $\frac{3}{4}$ inch thick, and rested upon a bed of 3 inches of concrete. The work had been executed partly by the Limmer Company, the French Company, and Leopold Stiebel. Where the paths were narrow and the stream of traffic persistent in one track, the concrete was making its appearance in small patches. Sometimes in wide paths the stream of traffic was persistent next the fence line, and in these cases the path was apt to wear out. He would suggest that it would be advisable in such instances to lay an extra thickness. Of course, the fall would influence the traffic; if too much fall the traffic would be almost sure to keep to the fence line. It had been said that the quality of the Val de Travers asphalt was proved by its wearing to a film, but that was not peculiar to that asphalt, as the Limmer Company's asphalt behaved in precisely the same way. Common asphalt was more easily fractured, and would not wear to a fine film.

Mr. Alfred Davis observed that the compressed asphalt blocks used in Paris were stated to have been unsuccessful. In the United States a block was made of refined and tempered Trinidad asphalt and finely crushed limestone, thoroughly heated and mixed in about equal proportions, and afterwards subjected to a uniform pressure of 1 ton to the square inch, or about 50 tons to the block. The standard size was 12 inches long, by 4 inches wide, by 5 inches deep. The blocks had been laid in several of the New England States, and he believed were being extensively used in New York, Philadelphia, and other American cities. He had seen a piece of this roadway in Philadelphia, after six years' wear, and it appeared in first rate condition, although the blocks were inferior to those now produced. In laying the compressed asphalt block road, a concrete foundation at least 4 inches thick was provided, over which a thin coating of gravel was spread; upon this bed the blocks were set close together and heavily rammed. The great advantage of this roadway was that it afforded a good foothold for horses, and at the same time possessed all the other advantages of asphalt roads as constructed in this country. The press employed in the manufacture of these blocks had a steam cylinder of 40 inches in diameter, worked with a pressure of 90 lbs. per square inch.

* *Vide* Annual Reports to the Board of Works for the Hackney district.

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There was an ingenious automatic arrangement for forcing the block out of the mould, and carrying it away to any desired spot for storage.

Mr. FREDERICK COX, Chairman of the Streets Committee of the City of London, said he had no connection with asphalt companies or wood paving companies; he was not an engineer, and he had no scientific knowledge whatever, but perhaps he might be permitted to make a few remarks as to the use of asphalt, past, present and future, in the City of London. The administrators of the City Commissioners of Sewers gave encouragement to every projector to send in any kind of asphalt or wood pavement that was likely to be permanently useful. About thirty different kinds had received a fair and proper trial; most of them crumbled into dust or proved to be utterly worthless, but there were a few that had stood a severe test. In his opinion the Val de Travers was the favorite company; but other companies had laid down asphalt with good results. Mr. Haywood, the engineer of the Commissioners, who probably had had more experience in roadways than any other person in the kingdom, reported, five years ago, that, after trying the various kinds submitted, he found that good compressed asphalt was the cheapest, dryest, cleanest, and most agreeable for the general purposes of traffic, and Mr. Cox ventured to say that if Mr. Haywood were giving his opinion now, it would be expressed in still stronger language. The Commissioners had carried out large paving works both with asphalt and wood, and probably the main reason that guided them in putting down so much wood was that the asphalt, especially when put down in great lengths, was found to be extremely slippery. In very dry or very wet weather the foothold of the horses was good, but when the pavement was muddy it was extremely inconvenient. It had been suggested that all that was necessary was to clean the streets, but what could be done with a place like Cheapside, when ten or twelve thousand vehicles passed over it every day? After eight o'clock in the morning it was useless to attempt to do anything of the kind. At six o'clock that very morning Cheapside had been thoroughly cleansed; at nine o'clock it had not dried, and it was in that peculiar state that, although quite clean, it was very slippery. Grit had to be thrown upon it in order to enable the horses to stand, and that state of things continued until the afternoon, when the rain came on and converted the grit into mud, which was probably so still, unless the heavy rain that had since fallen had washed it into the gullies. If cleanliness could be accomplished, in his opinion asphalt would be the best roadway for all the main streets; its use had, however, been attended with great difficulties, and the authorities had not yet decided which plan to adopt. To show the difficulties that were experienced, he might mention that three years ago the Commissioners commenced washing the streets, but they were threatened with an injunction from the Court of Chancery for washing concrete down the sewers. The Metropolitan Board of Works, who had the care of the main sewers, said, "It is all very well to wash your grit into our main sewers, but we must be careful what we do, because the Conservancy Board are threatening an injunction against us for raising shoals in the bed of the river." That, however, did not frighten the authorities in the City, who went to an expense of £10,000 in providing large catch-pits to the gullies in the City in order that the deposits might be removed, which was done almost daily. Then arose a qnestion about the water carts, which caused so much obstruction in the crowded streets that the police interfered. The authorities had endeavored to deal with that, and they had spent £20,000 during the last two years in erecting hydrants in every street and court in the City, both for the purpose of extinguishing fire and of watering the streets. Those hydrants were just completed, but had not been set to work. With regard to wood pavement, he believed it was one of the dirtiest and greasiest pavements ever put down in the City of London. Dirt was carried from it over 100 or 200 yards of the asphalt, and rendered that which was previously clean excessively dirty. He believed if the Commissioners could succeed in getting clean asphalt, so as to avoid slipperiness, wood pavement would make very little progress in the City of London, exept up gradients that were not suitable for asphalt.

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Mr. W. H. DELANO, in reply, said his experience in reference to scavenging was confined to Paris, where the work was effectually done both in wet and dry weather. Gangers were constantly at work, and they were paid about 3½d an hour. The gully holes placed under the curbs were large and the drains were roomy, so that the slush was easily passed down them. Hydrants had been erected all over the city, and after heavy rains they were used to flush the roadways and carry the mud into the drains. Of course it got into the river and formed banks, but that was the affair of other authorities. He would suggest that the catchpits to which Mr. Cox had alluded might be emptied by a pneumatic system of pumping into carts. Formerly mud carts were employed with revolving brushes to take up the slush; but he believed they had been superseded. It was evident that scavenging could not be done in London without considerable expense; but probably London mud, like Paris mud, contained fertilizing qualities, so that some set-off might be obtained. With regard to the granite sets in Paris to which Mr. Ellice-Clark had referred, he had given particulars of the cost, and also of the cost and maintenance of the macadam, in the appendix to his paper, and an interesting report had been presented upon the subject by M. Vauthier. As to the cracks which had been so frequently mentioned, he believed they resulted in nine cases out of ten from the concrete. If mastic asphalt was placed on wet concrete it would blister and sometimes crack, especially if the bitumen used as a flux to melt it was not well purified. Some engineers used straight joints to prevent cracks. He had also seen hoop iron put in between the concrete at certain distances when it was not too thick. It was always well that the asphalt, liquid and mastic as well as compressed, should be sufficiently thick. Unfortunately Municipal Boards often required things to be done cheaply, and hence the thickness of the asphalt was less than it ought to be. In Paris, where a fifteenth part had to be renewed every year, thickness was not such a desideratum. In the case of gritted mastic, the thinner the mastic the finer the grit should be. Where the mastic was thick, a coarse grit might be used, as shown by the specimen of asphaltic concrete on the table. There were few compressed footpaths in Paris. In 1874 he laid on the Pont Royal about 200 square meters of this material, under the orders of M. Allard, now Chief Engineer of the City of Paris, and it was now in good order. At one part it was laid $\frac{9}{16}$ inch thick, in other parts $\frac{3}{4}$ inch, and in others 1 inch. It had a better appearance than mastic, but it cost more, because the thickness was greater. The specific gravity of compressed and mastic asphalt was about the same, but the grit put into the mastic made it harder than the compressed material. The statement that asphalt neither contracted nor expanded was certainly an error. Of course the laying down of footpaths with gritted mastic depended a great deal upon the climate. In Marseilles the workmen would put into the cauldrons as much grit as they did asphalt, making a stiff mixture, which required great muscular strength to lay down $\frac{9}{16}$ inch in thickness, but when it was laid it answered very well. No practical worker of asphalt would ever use compressed asphalt as a coating for masonry, because it had not sufficient elasticity. Coatings of masonry were generally put down $\frac{9}{16}$ inch thick, and they required a good deal of bitumen; sometimes the layers were vertical, at other times convex, and frequently had to be inserted in recesses in the mansonry prepared for the purpose. Portland slabs had been suggested as a concrete, but he did not think they would answer, because they would require concrete underneath to keep them level. He had been reproached for not having alluded to asphalt as a covering for roofs, but his experience having been limited to France, where such applications were well known, particularly in the south, he supposed that engineers in London who were familiar with such applications would themselves refer to them. The applications of asphalt were almost endless. He had just seen a veteran asphalter in London who had shown him some work that he had done at the Horse Guards stables forty years ago. Up to the 31st of December, 1877, the chief cause of the want of stability of the compressed asphalt roadways in Paris was owing to the hydraulic lime concrete being only 4 inches thick, covered with a

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lime mortar floating, whereas a layer of 6 to 9 inches of Portland cement without floating was indispensable. Since the 1st of January, 1878, Lobsann asphalt had been used instead of Val de Travers and Seyssel, as heretofore, which, according to the report of the Paris engineers, had not sufficient stability. Seyssel mastic was chiefly employed in France for footpaths and coatings for masonry, whereas Val de Travers had been more largely used for compressed asphalt roadways, although by no means exclusively. Wood pavement had not succeeded in Paris, the only important specimen on the patent plank foundation being the Rue St. George's, which was partially in a bad state, although subject only to light traffic. In several cases wood pavements had been taken up in Paris within the last eight years, and replaced with granite sets and compressed asphalt. Wood was not a material of invariable density like compressed asphalt, the heart being always harder and less absorbent than the outer rings. It had, however, the great advantage of comparative insonority, though vibration was perceptible, and it was excellent for inclines exceeding 1 in 50. He thought that sound oaken sets, with beveled edges carefully laid on good cement concrete, with ¼ inch joints filled in with pure asphalt mastic, would render good service for roadways in dry climates, but he doubted if any pure wood pavements would last in Paris or in London much over three years without costly repairs. The smell from rotting wood pavements saturated with the filth of large towns must be deleterious. It was well known in Paris that Sicilian asphalt had been taken out of the list of asphalts approved by the city engineers for roadways since 1872. He had been prohibited from employing about 1,500 tons from Ragusa, Sicily, for roads in Paris, and had used a good deal of it as ashlar. This rock was available for flags, staircases and balconies; it was susceptible of delicate carving for architectural ornaments. There were three qualities, one rich in bitumen, the second medium, and the third poor, the latter being a coarse-grained yellow stone with the appearance of sandstone. If it would last three years under heavy traffic in London without repairs, such a test would class it as a material for roadways. It was quite possible to make bad work with good materials, though the converse was not true. Still, when good asphalt, properly ground and heated and well laid by careful workmen, did not stand, it was almost always the fault of the concrete. Laying on wet concrete, or using burnt powder was sometimes a cause of failure. Sets of pure Seyssel and Val de Travers powder, compressed in a mould 4 inches square and 2 inches deep, had been successfully used in Paris, but there would be a difficulty in repairs; it was also cheaper to lay hot powder in large towns. Some artificial sets, 8 inches cube, composed, he believed, of gas tar mastic and gravel, had been laid last autumn in the Rue Neuve des Petits-Champs, at the angle of the Rue Vivienne. The piece had been frequently repaired, as the surface wore away and crumbled under the traffic, which was not heavy. He had no confidence in bituminous concrete for roadways, except when used as a foundation for compressed asphalt, instead of Portland cement concrete. With reference to the Seyssel and Val de Travers mines, he had hoped that the engineers who had worked them would have been present and given personal explanations. He might mention that the mines were easily worked; there was no chokedamp in them, and little water. The rock was blasted with powder, dynamite not being used because the asphalt was tenacious in its nature. It had been stated that the test of asphalt was its durability. His object in writing the paper was that any engineer, surveyor, or architect, in specifying asphalt might have some other test. Asphalt might be adulterated; but the tests he had given would enable an architect or engineer to satisfy himself. With reference to the question of nomenclature, "asphalt concrete" had been alluded to in Mr. Deacon's paper; but he was sure from the context that gas-tar concrete was meant, which was a different thing. Mr. Cowper also had referred to pitch and tar pavements; but pitch and tar were not asphalt. It was most important not to confound them in specifications, as their respective values and properties were widely different. Considerable areas of compressed asphalt

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had been laid in Berlin, Vienna, Pesth, Brussels, and New York, and he regretted that no engineer had described the mode of laying.

CORRESPONDENCE.

Mr. MAURICE BIXIO, President of the Paris General Cab Company, owning about twelve thousand horses and six thousand vehicles, gave the results of his experience as to the most suitable material for roadways for vehicular traffic. The worst pavement was porphyry (grey Belgian granite sets, 4 inches by six inches). Falls of horses were much less frequent on asphalt, macadam, or rough pitching (sets of Fontainebleau gritstone 8 inches cube). For the horses, falls on asphalt were less dangerous than on any other material. Beyond all doubt traction was less on asphalt than on any other pavement. His company had made many experiments on this subject, from which he would quote, at random, the following, relating to the French four-wheeled cab, weighing 658 kilogrammes (1,447 lbs.):

	Kilogrammes.	
Traction on rough pitching.....	16.37	(36 lbs.)
Traction on small sets.....	14.79	(32.5 lbs.)
	Min. Max.	
Traction on macadam.....	14.0 to 20.5	(30.8 to 45 lbs.)
Traction on compressed asphalt (Val de Travers)	12.79	(28 lbs.)

It was probable, though difficult to establish otherwise than by comparison, that the wear and tear of the different parts of a vehicle was less rapid on asphalt than on other pavements. But the comparison did not apply in its entirety to macadam, in which case the tires of the wheel and the horse shoes were the only parts that wore out more rapidly than on asphalt. The difference of wear was due to the jolting produced by sets, which naturally induced friction between all parts susceptible to that action. He thought that traction being less, fatigue to the horse would also be less; but that was only an opinion, and not based on actual experiment. Asphalt was excellent also for granaries and for lining wooden mangers. For the paving of stables his company had made few experiments with the material, but as far as they had gone they were well satisfied.

Mr. ERNEST CHABRIER wished to deprecate a practice which had been tolerated for some time in the depots of the City of Paris, viz., the mixture of several kinds of asphalt, with a view to obtain an average quality which would be supposed capable of meeting general requirements. The principal quality to be sought for in rock asphalt for laying on roads was, the greatest possible homogeneity in the grain of the limestone, and equal regularity in the amount of the bituminous matrix. The greater this uniformity the longer would be the endurance of the asphalt roadway. He would illustrate this by referring to the fact, well known by all engineers concerned with roadmaking, that a mixture of hard with soft metal formed a less enduring surface than one of the softer material alone. The uniform wear of all parts maintained cohesion, which, on the contrary, was rapidly destroyed when a piece of hard stone was, from continual vibration, displaced, without being crushed, thereby leaving a hole. When asphalt rock was not suitable for road surfaces it was either too poor or too rich. In the first case the particles did not cohere; in the second the carriage wheels sunk into the material. The practice had been allowed of mixing these two kinds of rock in proportions impossible to be accurately determined, the process being left to the rule of thumb of the workmen. It was only reasonable to suppose that the requisite care was not always bestowed, and in case of bad mixing bad work would result, and a much more rapid deterioration must be expected, on account of the non-homogeneity of the material. It was, therefore, most important that persons proposing to lay down asphalt roadways should, above all things, get the particular rock best suited for the purpose, and further, should seek to obtain it of as even texture as possible.

Mr. LAVALLARD, Director of the Stock and Forage Department of the Paris General Omnibus Company, gave some information relative to the traction of heavy vehicles on asphalt carriageways. The standard omnibus of the Paris Company weighed from 1.67 to 1.77 ton empty, and from 3 to 3.6 tons when full. The diameter of the fore-wheels was 4½ feet,

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of the hind-wheels 5 feet, the width of the tires being 2¼ inches. The new three-horse omnibus weighed, when full, from 5 to 5½ tons; the diameter of the fore-wheels was 3⅜ feet, and of the hind wheels 5 feet, the width of tires being 3⅛ to 3½ inches. The company's tramway omnibus* weighed, when full, 6 tons, and the diameter of the wheels was 3⅛ feet throughout. The result of daily experience showed that when the weather was not very warm and the asphalt remained hard, traction on this material was less than on ordinary roadways; but that when the asphalt became softened, by the heat of a fierce sun, traction became considerable and augmented with the rise of the thermometer and the weight of the vehicle. When the asphalt was either dry or wet it afforded a good foothold for the horses. But when the asphalt was beginning to get wet or beginning to dry the horses had much difficulty in keeping up. Under such conditions the asphalt was slippery, and the fall of the horses became frequent. This did not, however, affect the traction of the vehicles, which still remained less than on other roadways. The wear and tear of tires, axles, harness, &c., was less on asphalt because shocks were imperceptible. Although, under the conditions named, horses fell more frequently on asphalt than on granite sets, the injuries received were less serious. It, however, resolved itself into a question of shoes, and he thought the adoption of the Charlier horse shoe had met the difficulty. His company had found that asphalt succeeded perfectly as a flooring for granaries and forage stores, but not so well for stables, where it had in most cases to be abandoned, owing to the weight of the horses (from 10 to 12 cwt. each) causing depressions in the material when softened by the warmth of the recumbent animal. The urine collected in these holes, and, moreover, the asphalt was too smooth for the straw, which was always found kicked out behind the stall. Perhaps for horses of a lighter build the inconvenience would not be so great. Latterly they had had reason to believe that the consistence of the subsoil had some influence on the question, because they had stables wherein asphalt floors laid ten or twelve years ago were still in good condition. The cost of maintaining the asphalt laid along their tramways was 1 franc 20 centimes per square metre per annum.

PROPOSED SYSTEM OF INCLINED PLANES FOR MOUNTAIN ROADS.

By ED. M. ROGERS.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

AT present the railroad system of the world has reached an extent of 123,000 miles, involving in its construction an expense of $11,255,000 and the consumption of more than one-half the total iron production. This excessive cost is due, in a great measure, to the necessity of using comparatively light grades rather than making the roads conform to the surface of the ground.

With a view of obviating this difficulty many ingenious systems of gravity railroads have been proposed, with varying success, but they are all open to serious objections which have heretofore prevented their general introduction. With very few exceptions the overcoming of steep gradients is confined to the friction of smooth drivers on smooth rails.

At a very early date in the history of railroads, the discovery of coal in the Lackawanna Valley directed the attention of engineers to the problem of its transportation, across the mountains, to a seaboard market. The result of their investigations was the construction of the noted gravity system of the Delaware & Hudson Canal Co. This system involves two independent sets of inclined planes, each set being arranged in the order of a short, but steep plane, followed by a

* The vehicle used on the tramways of the Paris Omnibus Company is not a car as usually understood, but merely a big omnibus on flanged wheels. The tramway companies use cars of the same character as those in London.

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long one, the inclination of which is reversed and is only sufficient to overcome the friction of the cars. At the summit of these planes are situated stationary engines, provided with suitable drums and endless wire ropes. Arriving at the foot of a steep incline, the trains are attached to the rope and elevated to the summit by the action of the engines, being then in position to descend the long inclines in virtue of their potential energy.

The second set, which is in some places several miles distant from the first, has its planes reversed and is intended for the return of the empty cars.

This is, doubtless, the cheapest method of transportation, through mountainous districts, provided there is traffic enough over the line to keep the stationary engines in constant use; for what would represent the friction of a train for a long distance on a supporting grade is concentrated in overcoming the gravity of a short plane.

Yet, notwithstanding the utility of this method, in special, and the entire railroad system, in general, there is still a want felt which calls for, and has, in some measure, received the attention of engineers of to-day. I speak of lateral roads through mountainous districts intended as feeders of main trunk lines, over which the traffic is not sufficient to warrant the expense attending the construction of long lines, with light grades, or the operation of gravity roads with stationary engines and rope haulage.

Since it is the purpose of this paper to propose and discuss a system of planes for lateral roads, perhaps it will be well to mention some of the kindred devices already in operation, in order to bring them into comparison with the proposed plan.

In June, 1876, an article appeared in this MAGAZINE by Mr. Henry Handyside, stating the problem of inclined roads, and proposing to solve it in the following manner:

The greater portion of the line was to be constructed with such a grade that the ordinary locomotive might be able to draw over it trains sufficiently large to accommodate the traffic of the region through which it passed. But, in order to overcome the required elevation, occasional planes, not exceeding one in six, were to be thrown in at such places as the character of the country might warrant. A plane of one in six is the maximum inclination over which a locomotive can proceed, without a load, and in all kinds of weather. Since, then, none of the planes were to exceed this limit, the locomotives could always climb them, and it only remained to provide suitable means of elevating the trains. To accomplish this, each locomotive was to be provided with winding gear and steel wire rope, driven by auxiliary engines. In addition to this they were to carry powerful gripping struts which, by their action on the rails, might be capable of holding the entire train. Arriving at the foot of a plane the engine was to be uncoupled and proceed up the hill, at the same time playing out the wire rope from its winding drum. At the summit it was to be anchored by means of the gripping struts, thus virtually changing the entire machine into a stationary winding engine, by the action of which the train might be elevated.

This method was practically tested in England, and met with some success, though its introduction was very limited, and, I believe, it has since been abandoned.

Another method which has received some attention, but which has not, as yet, been practically tested, is briefly as follows:

The grade of the road is arranged like that of Mr. Handyside; that is to say, there are no inclines so steep but that a locomotive, detached from its train, can climb them. The method of operation is also similar to that above described, the only essential difference being in the manner of changing the locomotive into a winding engine. In this case, upon arriving at the summit of a plane the locomotive is anchored over a pair of friction drums on which the drivers act, causing them to rotate and put in motion a set of winding gear, by the action of which the train is elevated.

The main advantage which this system offers over that of Mr. Handyside is, perhaps, the difference in expense between the equipment of the planes with suitable drums and gear in the one case, and providing each locomotive with the necessary appliances, in the other case. This would, of course, vary

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under different circumstances, and perhaps there can be no general comparison between the two.

The toothed-rail system used on the Mt. Washington and the Rigi Railways is so familiar that mere mention of those celebrated roads will stand in lieu of a full description. The name "third grip rail" used on the Mt. Cenis Railroad, explains itself.

Many other ingenious methods of overcoming elevation have been proposed, but explanations of them, although perhaps interesting, would not be compatible with the limits of this paper. Let us, therefore, proceed to explain the device proposed in this paper.

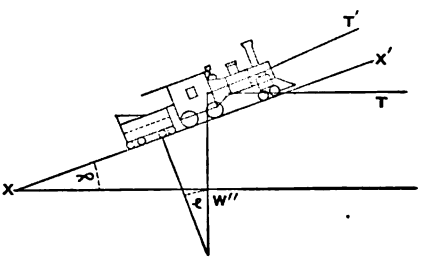
In order to make plain the problem under consideration, it may be repeated in a more specific form. Let us suppose that a trunk line wishes to extend a branch into some mining district where the elevation to be overcome is great, but the character of the country such that most of it may be mastered in one or two short inclines, if safe and economical means of climbing them can be devised.

In overcoming ordinary grades, and in all attempts to climb steep gradients, the real process is a change of kinetic energy, or energy of motion into potential energy, or energy of position. In all locomotive systems now in operation, no attempt is made to utilize this potential energy after it has been attained. On the contrary, outside of the mere descent, it is a troublesome element which has to be overcome by brakes. If it can be put to practical use its superiority over kinetic energy, which must be generated for the occasion, is manifest.

Let us suppose that we have a train of loaded cars, whose weight is P, at the summit of a steep incline, and let it be connected with a counter weight, enough lighter than itself to provide for friction. The train descends and the counter weight ascends, and is then in position to eert its potential energy in elevating another train, provided it is lighter than the first. When the traffic down the plane is greater than in the opposite direction, the system may be operated without the aid of an outside motor. It is, indeed, a method very often used in mining operations where ore or coal is to be transported from a higher to a lower evel.

If to the train at the summit of the incline a locomotive is attached whose weight is W, and if, for the moment, friction is neglected, it is evident that the entire train will be capable of elevating a counter weight weighing $P+W+W'$, W' being an additional weight, due to the traction of the locomotive, and depending upon the inclination of the plane. The counter weight will, in turn, be capable of elevating a dead weight $P+W+W'$ or a train weighing $P+W+2W'$ provided it is also drawn by a locomotive. By properly choosing the inclination of plane and weight of counter weight, the system will be under the full control of the locomotive, and entirely independent of the preponderence of the traffic down the plane. But before discussing this case let us determine the value of W'.

The adhesive power of a locomotive is evidently the limit of its tractive power, and may be substituted for it in determining the maximum load. It varies greatly according to the condition of the track, but may be safely taken at one-fifth the insistent weight on drivers multiplied by the cos. angle of inclination.



Let us now investigate the load which a locomotive will draw on a level, and then extend the investigation to inclines suitable for systems intended to overcome great elevation.

Let W'' = total weight of train.
" T = traction of locomotive, on level.
" a = angle of inclination.
" f = coefficient of friction, of train.
" T' = traction of locomotive on plane.

Projecting all the forces upon the axis

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XX′, the general equation of motion will be

$$(1)\quad \Sigma X=\theta(W''\sin\alpha+W''f\cos\alpha) -T\cos\alpha=o$$

θ being a variable whose value determines the direction of the motion. That is to say,

When $\theta=1$ there is equilibrium.
" $\theta>1$ there is motion up the plane.
" $\theta<1$ there is motion down the plane.

If G=weight of locomotive and tender, ρ= percentage which rests on drivers, and we take friction at 8 lbs. per gross ton, T′=T cos α and eq. (1) becomes

$$W''\sin\alpha+W''\frac{8}{2240}\cos=\tfrac{1}{5}\rho G\cos\alpha$$

$$\text{or}\quad W''\tan\alpha+\frac{8W''}{2240}=\frac{\rho G}{5}\quad\ldots\quad(2)$$

When $\alpha=o$ and $\rho=.6$ (which will be the case if the locomotive has four driving wheels) tan $\alpha=o$. Then (from eq. 2)

$$W''=33.6\ G.$$

That is, under the assumed data, the locomotive will pull 33.6 + its own weight on a level. This is a superior limit since $\theta>1$.

The load which the locomotive will pull on any grade may be found by substituting the proper value for tan α in (eq. 2), and to find the maximum grade over which the locomotive will travel when detached from its train, it is only necessary to substitute W″=G in the same equation

$$G\tan\alpha+\frac{G}{280}=\frac{.6G}{5}$$

whence, tan α=.11642 which corresponds to a grade of 1 in 8.5.

If the locomotive is so constructed that the entire weight is thrown upon the drivers, $\rho=1$ and the grade may be increased to 1 in 5.

Assuming the inclination to be one in nine, and supposing the locomotive to be at the summit, it will (according to what precedes) elevate a counter weight, the weight of which may be determined from the formula

$$Y=G+W''-2F-F'\quad\ldots\quad(3)$$

In which

Y = weight of counter weight.
G = " " locomotive and tender.
F = friction " " " "
F′= " " sheave journals, ropes, etc.
W′=total load which locomotive will draw upon the incline.

W′ may be determined from eq. (2) by making tan $\alpha=\frac{1}{5}$

$$\tfrac{1}{5}W''+\frac{W''}{280}=\frac{.6}{5}\ G$$

$$\text{or}\quad W''=1.05\ G.$$

Since we have assumed 8 lbs. per gross ton to be the amount absorbed by friction of train,

$$F=\frac{8G}{2240}\quad 2F=.007\ G.$$

In determining the last member (F′) it is only necessary to obtain the initial friction, or that which must be overcome in order to set the system in motion. Since the pressure on journals is 2 sin α =.14 Y, and the coefficient of axle friction for wrought iron on brass is .075, the initial friction will be .14 Y × .075= .105 Y. Now suppose diameter of sheave=10 diameter journals, then the force at circumference of sheave necessary to overcome friction of journals =.1 ×.105 Y=.0105 Y.

Substituting these values of F, F′, and W″ in eq. (3)

$$Y=G+1.05\ G-.007\ G-.0105\ Y$$

$$\text{or}\quad Y=2.02\ G.$$

This calculation does not take into consideration either the weight or rigidity of the rope, but is sufficiently accurate to show that the system will be under full control of the locomotive, provided the inclination does not exceed one in nine, and the counterweight is no heavier than 2 G, for it can always proceed up the plane and manage the counterweight unassisted. Bearing this in mind, the reasons for the following plan for a lateral road will be manifest:

Let the mean portion of the line be built on an ordinary supporting grade, but at such places as the character of the country may warrant, let occasional planes, not exceeding one in nine, be thrown in, and let each of these be provided with suitable counterweights, weighing no more than 2 G. Then all trains

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weighing less than 3 G may proceed over the planes without delay, but should they exceed this limit it will be necessary to divide them, and make two trips over the plane. If, however, the traffic can be arranged so that the counterweight will always be in position for the next train, that is, if the trains alternate in direction, it may be made much heavier and the angle of inclination may also be increased.

To illustrate this let us take an extreme case. For instance, take $\alpha=45°$ then tan $\alpha=1$, and from eq (2) we obtain the value of $W''=.12$ G, which may be interpreted thus: On a plane whose inclination is 45°, a counterweight weighing .88 G will be required to elevate a locomotive weighing G, provided the full traction of the engine is utilized. As soon as the inclination has passed the limit one in nine, the system is no longer under control of the locomotive, and there is no further necessity of limiting the weight of counterweight. But (in the case $\alpha=45°$) the trains passing down the plane must weigh at least Y—.12 G, and those passing up the plane will be limited to Y+. 12 G.

In most cases these conditions would be found inconvenient if not impossible, and the use of inclinations greater than the angle of adhesion would be expedient only under very exceptional circumstances.

The construction and equipment of planes suitable for this system would be, in most cases, neither difficult nor expensive. Perhaps it will be well in this connection to give a few details. However, before doing so it will be necessary to assume data for a particular case.

Since the value of ρ exerts so great an influence upon the maximum grade which may be given to the plane, it is very essential to use a locomotive, the weight of which is well concentrated upon the drivers. This effect is best produced in what is known as a "tank engine;" and in the following details it will be assumed that such an engine is used.

Now, since the track is exposed to all kinds of weather, a poor, though not absolutely the worst condition, of the rails must be taken to compute the inclination of the plane. For frost, the adhesive power is $\frac{1}{4}$ G cos α, while for thoroughly wet rails it is $\frac{1}{4}$ G cos α and for dry rails it rises as high as $\frac{1}{3}$ G cos α. To obtain the maximum utility it would, of course, be inexpedient to assume a factor of adhesion providing for snow, for since the planes are short it would, doubtless, be more economical to clear the rails than submit the system to such unfavorable and extreme conditions. In the previous discussion the factor $\frac{1}{4}$ was used, and the value of ρ was taken at .6, thus providing for frosty rails and a tank locomotive. Under these suppositions, the inclination was found to be about one in nine. This is a somewhat smaller inclination than that assumed by Mr. Handyside and others, which is probably due to the fact that it was derived under the assumption that the rails are in poor condition.

In order to illustrate the problem let it be proposed to overcome an elevation of 200 feet, and assume available ground for a straight incline which will be 1800 feet long, since the inclination is one in nine.

From what has proceeded it will appear that when the rails are covered with frost the weight of the counterweight is limited to 2 G, or in this case, 80 tons. If, however, the rails are thoroughly wet this weight may be increased to 120 tons, and for dry track, to 125 tons. To provide for this difference and always obtain the maximum effect of the system, it is only necessary to divide the counterweight into sections weighing respectively 80, 40 and 5 tons. In good weather the total weight may be elevated by the locomotive, but when the rails become slippery the sections must be uncoupled, and the 80-ton weight alone used. A good form of counterweight, and one which would combine economy in first cost, compactness, and durability, would be simply pig iron cylinders, roughly cast around axles and fitted with ordinary car wheels. These cylinders might be connected together in groups of two, by means of side beams carrying suitable boxes for the axle journals, and the groups, in turn, coupled into a train of the requisite weight.

In cases where the proper excavations could be cheaply made, counterweight might be made less with a somewhat narrower tread than the cars, and run on a track in a covered trench, underneath the main track, thus reducing, in a great

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measure, liability to accident, and securing the counterweight against all obstructions.

COMPARISON.

In the absence of accurate data it would be a difficult matter to make a close comparison between the cost of a road built on this plan, and one in which the same elevation is overcome by an ordinary supporting grade; but the following is a rough approximation to the comparative merits of one plane of the gravity system, and a corresponding portion of the common road.

As before, let it be required to overcome an elevation of 200 feet, and assume available ground for incline of one in nine, and also for the development of a supporting grade. The length of the former will be 1800 feet, while that of the latter will depend upon the grade assumed. As a gravity system would be adopted only in mountainous districts, curvature would exert considerable resistance, and should be taken into account. This is easily done, in case of the plane, by assuming the weight of counterweight to be enough greater than that of the maximum train, to overcome all resistances. Five tons difference, which has been assumed in the following discussion, is not only sufficient to do this, but would also render some assistance to the locomotive. In the case of the supporting grade, however, these resistances must be overcome by the locomotive and must be considered.

There is a custom of equating or compensating for curvature on supporting grades, by deducting from the rate of inclination an amount equal to from $\frac{5}{100}$ to $\frac{8}{100}$ of one per cent. of the distance for each degree of curvature. Thus, if we assume a nominal grade of 100 feet per mile (1.9 feet in 100 feet, or a 1.9 per cent. grade) it must be flattened $\frac{5}{100}$ to $\frac{8}{100}$ (an average of .06) feet in every 100 feet for each degree of curve, or .06 $\times 52.8 = 3.168$ feet per mile, for each degree in 100 feet. Now, let us assume something like the ordinary characteristic of alignment in a mountainous country, say a total deflection of 180° in each mile of distance or 3.03° in each 100 feet. This will call for a reduction of $3.03 \times 3.168 = 9.6$ feet per mile.

The absolute grade is then $100 - 9.6 = 90.4$ feet per mile, and the distance required to overcome 200 feet elevation is $\frac{200}{90} = 2.2$ miles. This means that overcoming an elevation of 200 feet and a total curvature of 180° per mile is equivalent to overcoming $100 \times 2.2 = 220$ feet on a straight track. We may therefore consider our grade as 100 feet, and distance as 2.2 miles, and pay no further attention to curvature. In this case the length of the supporting grade is

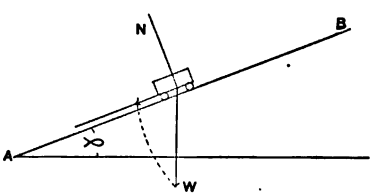
$\frac{2.2 \times 5280}{1800} = 6.45$ times as long as the equivalent gravity plane.

This will enable us to roughly approximate to the relative cost of the two systems, but in order to make a fair comparison of their merits, we must also take into consideration the amount of work which can be done on each in the same time.

To arrive at this result, let us first determine the time required to take the maximum train over the plane, and also the time in which the same locomotive, drawing the same load, can climb the grade.

Let H = the absolute horse power which the locomotive is capable of imparting on a level road. (If the cylinder power is large enough, H is dependent upon the adhesive power, which varies as the cosine of the angle of inclination. On an incline, therefore, the power = H cos a)

Let a = inclination of plane.
" s = length of plane, in feet.
" t = time required to pass over the distance s.
" 8lbs. = friction per gross ton, on level track.
" W = load, including locomotive, in tons.



We may derive a general expression for t from the following consideration:

Resolving W in the direction AB and taking friction $= \frac{8}{2240} N = \frac{W \cos a}{280}$ we

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have for the force which the locomotive must overcome

$$W \sin a + \frac{W \cos a}{280}.$$

Now since work is pressure into distance, the work absorbed in taking the load up the plane is,

$$s\left(W \sin a + \frac{W \cos a}{280}\right)$$

foot tons, or if the ascent requires t minutes.

$$\frac{s\left(W \sin a + \frac{W \cos a}{280}\right)}{t}$$

foot tons per minute.

Since one horse power = 33000 foot pounds $= \frac{33000}{2240}$ foot tons, per minute, it requires

$$\frac{2240 s\left(W \sin a + \frac{W \cos a}{280}\right)}{33000 t}$$

horse power to draw the load up the plane. But the actual horse power expended by the locomotive is H cos a. Consequently

$$\frac{2240 s\left(W \sin a + \frac{W \cos a}{280}\right)}{33000 t} = H \cos a$$

or

$$t = \frac{2240 s\left(W \sin a + \frac{W \cos a}{280}\right)}{33000 H \cos a} = \frac{2240 s\left(W \tan a + \frac{W}{280}\right)}{33000 H}$$

If H is constant we may substitute

$$A = \frac{2240}{33000 H}$$

whence

$$t = A\left(W \tan a + \frac{W}{280}\right) \qquad (a)$$

In this formula no account is taken of the pressure of the air; but, since the velocity on the grade must be greater than that on the plane, this omission will favor the supporting grade. If the same condition of track is assumed in both cases, it makes no difference whether it be wet or dry, for the power of the locomotive will be equally limited by slippery rails. Let us then assume that the entire counterweight (125 tons) is used, and that the maximum train weighs 120 tons, exclusive of locomotive. The extra five tons of the counterweight, will easily overcome the friction of the system and keep the train pressing against the locomotive. Therefore, in the case of the plane, it is only necessary to find the time in which the locomotive, uncoupled from its load, will ascend the plane. This may be found in terms of H, by substituting in eq (a), W = 40 tons S = 1800 ft. and tan $a = \frac{1}{20}$.

Making these substitutions and reducing we find t = 8257 A.

In the case of the supporting grade, however, the locomotive must elevate, not only itself, but also the train (120 tons), making a total load of 160 tons. Therefore,

$$W = 160 \text{ tons} - \tan a = \frac{1.9}{100},$$

and $s = 2.2 \times 5280$.

From these values we obtain $t_1 = 41957$ A.

Hence

$$\frac{t_1}{t} = \frac{41957 A}{8257 A} = 5.08 \text{ or } t_1 = 5.08\, t$$

That is—the time required to ascend the grade is 5.08 times as much as that required to ascend the plane. Now let us suppose that the descent of the plane occupies just as much time as the ascent, and that 2.08 t is consumed in delays at the top and bottom. The train can proceed up the plane, the locomotive descend, elevating the counterweight, and re-ascend with another train, in the time that it would require for one train to pass over the grade.

Thus, at least twice as much weight can be transported over the gravity plane, in the same time, as over the supporting grade.

Let us now assume an average cost of construction, exclusive of equipment, in a mountainous country, say $30,000 per mile, and endeavor to arrive at the relative expense of the two systems. At this rate the cost of the supporting grade would be $66,000. If we assume that the cost of grading and tracking the gravity plane to be one and a-half times as much as the same length of main line, we will have 1,800 feet of inclined plane to construct at a cost of $45,00

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per mile. The following is a rough estimate of the cost of a gravity plane. As it is made for comparison with the cost of an equivalent supporting grade, the items are assumed very high in order to be sure of covering the expense.

1,800 feet of track @ $45,000 per mile	$15,340
Counterweight about	6,000
Steel wire rope	2,000
Extra work at top and bottom of plane	1,500
Sheaves, frames, etc.	1,000
	25,840
For contingencies, etc.	7,160
	$33,000
Cost of supporting grade	66,000

The result of the above comparison may be briefly stated thus: Under the assumed data, the gravity plane is capable of doing twice the amount of work in the same time, while its original cost of construction is only one-half as much as an equivalent supporting grade.

It will be noticed that very liberal allowances have been made for delays at the head and foot of the incline, and for the friction of the gravity system. The friction of train, sheaves, etc., has been allowed for in determining the inclination. And the extra five tons weight of counterweight over that of the maximum train is not only sufficient to overcome any resistance due to curvature, but would render some assistance to the locomotive.

In conclusion, it may be added that in the construction of such a system due reference should be paid to the arrangement of the grades so that the maximum train, on that portion of the line which is arranged as a supporting grade, should be able to pass over the planes. Or the arrangement might be made with reference to the division of the trains at the foot of the planes, in which case it would be necessary to make two or more trips over the planes for each train.

THE RIVERS OF CHINA.

THE YANG-TSE, THE YELLOW RIVER, AND THE PEI-HO.*

From "Nature."

THESE three rivers form conjointly the great river system of China. Although at the present day each of them runs its separate course to the sea, there is good reason to believe that several centuries since they were united by a number of connecting branches, in a manner somewhat resembling the junction of the Ganges and the Brahmapootra in our own time. Such is the inference to be drawn from an ancient Chinese map, copied by Alvarez Semedo, a Portuguese Jesuit, and which must be assigned to a time preceding that of the construction of the Grand Canal by Ghenghis Khan in the beginning of the thirteenth century.† Linked together as these rivers were in the past, a brief consideration of their present condition will prove that they are laboring towards the same end in our own day. But before proceeding to examine them in their conjoint character, it will be necessary to consider briefly their leading hydrological features.

I.—The Yang-tse—the largest and most important of these three rivers—has a course of about 3,000 miles, and drains an area which is variously estimated between 750,000 and 550,000 square miles; for my own calculations I will adopt the mean of these two estimates, namely, 630,000 square miles. Its waters, commencing to rise in February and March, reach their highest level in the month of June or July; and here they remain with occasional fluctuations till the end of August or the beginning of September, finally reaching their lowest level towards the close of January.

With regard to the discharge of water of this river, Capt. Blakiston* has esti-

* The author, Surgeon H. B. Guppy, of H.M.S. "Hornet," writing from Yokohama, February 11, says: "I forward to you by this mail a paper containing the results of observations I have made during the last two years on the subject of the Yang-tse and the Pei-ho, together with similar information as regards the Yellow River. Looking on these three rivers as in reality one river system, I have embodied in one paper all the "data" concerning them; and have treated them both separately and in their conjoint character. I can answer for the accuracy of the various estimations, and have employed the usual methods in obtaining them."

† *Vide* a paper by Mr. S. Mossman on the "Double Delta of the Yellow River," published in the *Geographical Magazine* for April, 1878.

* "Five months on the Yang-tse."

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mated the average amount carried past T-chang, which is situated at about 960 miles from the sea, at 500,000 cubic feet per second; he founded this estimate on observations made during the months of April and June. When stationed at Hankow in the winter 1877-78, a place distant about 600 miles from the sea, I set to work to make a similar estimate of the water carried past that city for the twelve months included between May 1877 and May 1878. Having taken a line of soundings across the river and having ascertained the river's breadth (1,450 yards by sextant measurement) at a point below the union of the Han with the main stream, I commenced a series of observations on the rise and fall of the river water and on the force of the current, which combined with information received from the Custom-house and from other sources, supplied me with the necessary data for my calculation. The results are contained in the following table:

1877.	Surface current. Knots per hour.	Average depth. Feet.	Water-discharge. Cubic feet per second.
May 31..	2¼ ..	64 ..	846,336
June 30..	2¼ ..	61 ..	896,293
July 31..	3 ..	58 ..	1,022,656
Aug. 31..	3¼ ..	62 ..	1,275,381
Sept. 30..	2¾ ..	63 ..	1,018,248
Oct. 31..	2 ..	53 ..	622,997
Nov. 30..	1¼ ..	42 ..	308,560
Dec. 31..	1 ..	36 ..	211,584
1878.			
Jan. 31..	¾ ..	30 ..	141,085
Feb. 28..	1¼ ..	39 ..	412,620
Mch. 31..	1¾ ..	45 ..	396 720
Apl. 30..	2 ..	57 ..	670,016
			12)7,822,502
			651,875

We may therefore place the average water-discharge for the year at Hankow at 650,000 cubic feet per second. Now, estimating the area of drainage above Hankow to be about $\frac{11}{18}$ of the whole area, and assuming that the portion of the Yang-tse valley below Hankow drains off its waters at the same rate as the remainder of the river-basin, it follows that the average water-discharge for the whole river may be placed at 770,000 cubic feet per second.

With reference to the amount of sediment carried by the Yang-tse past the same city, I found as much as seven grains in the pint (nearly one drachm in the gallon) in the month of July, when the river was at its height; while in March, when the river was low, I found as little as three-fifths of a grain per pint. The average proportion of sediment during the twelve months in question I estimate at four grains in the pint (a little over half a drachm per gallon). This represents a proportion of $\frac{1}{2188}$ by "weight," or (taking the specific gravity of the dried mud at 1.9) of $\frac{1}{4157}$ by "bulk" of the average discharge of water. It is thus easy to obtain the total amount of sediment carried during the twelve months past Hankow, namely, 4,945,280,250 cubic feet: but to allow for the amount of mud a river pushes along its bed, one-tenth must be added according to the principle laid down by Messrs. Humphreys and Abbot in the case of the Mississippi. This will bring the total annual discharge of sediment at Hankow up to 5,439,808,275 cubic feet, or at the rate of 172 cubic feet per second. Now, assuming that the drainage area below Hankow supplies the same relative amount of sediment as the remainder of the catchment basin, I estimate the total amount carried down to the sea annually at 6,428,858,255 cubic feet.

The removal of this amount of sediment from an area of drainage of 650,000 square miles represents a lowering of the surface at the rate of one foot (of rock) in 3,707 years. This is therefore the rate of "subaërial denudation" of the valley of the Yang-tse as far as concerns the quantity of sediment removed. Of the proportion of solids in solution, I have had no opportunity of judging, but that the soluble matter is in considerable quantity is rendered probable from the extensive limestone districts traversed by this river.

II.—The Yellow River or the Hoang-ho has derived the appellation of "China's Sorrow" from its frequent destructive inundations. It runs a course of about 2,500 miles; but, unlike the Yang-tse, its lower course has frequently shifted in the course of ages, and although it opens at the present day into the Gulf of Pechili, only a quarter of a century has passed since it emptied its waters into the Yellow sea.* The mountainous district of the province or Shantung has in truth been the chief means in deflecting

* *Vide* Mr. Mossman's paper, already referred to.

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the waters of this great river on more than one occasion during the historical era from the Gulf of Pe-chili to the Yellow Sea and vice-versa.

With reference to the quantity of water discharged by the Hoang-ho I have had no opportunity of personal observation. We have, however, an estimate not only of the water discharge, but also of the sediment, which Sir George Staunton supplies us in his account of Lord Macartney's embassy to China in 1792. It was calculated that at the place where the British embassy crossed the Yellow River—its junction with the Grand Canal—the water was carried past at the rate of 418,176,000 cubic feet per hour, or 116,000 cubic feet per second. The method employed in ascertaining the quantity of sediment was the measurement of the amount of mud deposited from a gallon and three-quarters of water when allowed to stand. From this experiment it was concluded that the sediment was in the proportion of $\frac{1}{100}$ of the original bulk of the water, and the annual discharge of sediment was assessed at 17,520,000,000 cubic feet.

However carefully these observations may have been made, and however near they may approach the actual discharge of water and of sediment at the time in question, it seems to me that one is hardly justified in accepting the result of a single observation as typical of the average state of things throughout the year; and yet Sir George Staunton's estimate has never, as far as I am aware of, been questioned. A single glance at the foregoing table will convince one of the little dependence that can be placed on a solitary estimation; it will be there seen that the Yang-tse discharged nine times as much water when at its highest level in August as it did during the month of January, when its waters occupied their lowest level.* Or if the question of sediment is considered, to which the same objection would apply, I have the greatest diffidence in accepting Sir George Staunton's estimate as being of any value, except as a trustworthy result o a single experiment; and yet, even considered as the maximum of the whole year, the result is rather a startling one. While the greatest amount of sediment I found in the water of the Yang-tse was seven grains in the pint, and in the case of the Pei-ho—as will subsequently be noticed—fifteen grains in the pint, Sir George Staunton estimates the sediment of the Yellow River at over eighty grains in the same measure of water. Even the muddy waters of the Ganges do not contain more than twenty grains of sediment in the pint of water.

It is therefore not with any surprise that I find the "subaërial denudation" of the Hoang-ho is estimated* at less than half that of the Yang-tse, namely, one foot in 1,464 years. This estimate only refers to the amount of sediment removed, and yet I cannot but consider it as very liable to correction by some future observer. As this is the only calculation that has ever been made, as far as I am aware, with reference to the quantities of sediment and of water discharged by the Yellow River, I am perforce obliged to accept it as *pro tanto*.

III.—The Pei-ho drains the great plain which constitutes the province of Pe-chili. Its length is said to be about 300 miles, but the lower part of its course below the city of Tientsin is so tortuous that a distance of thirty miles overland is converted into fifty by the river. It is at Tientsin that the Pei-ho proper and the Yu-ho unite together to form the main stream; the latter is generally known by Europeans as the Grand Canal, but as a matter of fact the canal joins the Yu-ho about 150 miles to the southward. During the three winter months—December, January, and February—the Pei-ho is usually frozen over, the ice having a thickness of about eighteen inches; in the same season there is generally a large quantity of ice in the Gulf of Pe-chili, which may completely fill up the head of the gulf.

With reference to the water discharge of this river, I was enabled while wintering at Tientsin during the season 1878-79, to collect some "data" for its estimation during the four months from December to March. Although my estimate strictly applies to but a third of the year, still from the limited rise and fall of the water during the different seasons (it never exceeds six feet) I feel pretty confident that it fairly represents the average rate of discharge during the whole

* In the case of the Ganges at Ghasepoor the proportion is as 1 to 14.

* *Vide Nature*, vol. 18, p. 288.

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year. The breadth of the river at the place of observation below the city of Tientsin was 280 feet. The following table contains the results of my calculations:

1878.	Surface current. Knots per hour.	Average depth. Feet.	Water discharge. Cubic feet per second.
December	1½ ..	14 ..	6,355
1879.			
January..	¾ ..	14½ ..	4,389
February.	1⅝ ..	16 ..	9,684
March...	2 ..	14 ..	10,592
			4) 31,020
			7,755

We may thus place the average discharge of water for the whole year at about 7,700 cubic feet per second.

Now with regard to the amount of sediment carried past the city of Tientsin: I found the average quantity during the four months in question to be about five grains per pint. (It varied much at different times, for I found as much as fifteen grains in the middle of March, while in the months of January and February it did not equal a grain in the pint.) This represents a proportion of $\frac{1}{1750}$ by "weight," or $\frac{1}{3325}$ by "bulk" of the average discharge of water; and following the same method of calculation as was employed in the case of the Yang-tse, I estimate the annual discharge of sediment for this river at 80,000,000 cubic feet.

Now the removal of this bulk of material from an area of drainage, which I estimate at 55,000 square miles, represents the lowering of the surface of one foot in 25,218 years. This is the rate of "subaerial denudation" of the Pei-ho basin, omitting of course the question of the solids in solution.

To show the rank that these three rivers hold in the fluvial system of the globe, I have subjoined a list of fourteen other rivers which gives the quantities of water and sediment discharged by each, as well as the rate of subaerial denudation, as far as I have been able to ascertain.

	Water discharged per second.	Sediment per annum.	Subaërial denudation.
	Cubic feet.*	Cubic feet.	
Amazon	2,458,026	—	—
Congo	1,800,000 (By Behm and Capt. Tuckey.)	—	—
Yang-tse	770,397 (By myself.)	6,428,800,000 (By myself.)	1 foot in 3,707 years. (By myself.)
Plate	700,000 (By Mr. Higgin and Mr. Bateman.)	1,543,500,000 (By Mr. Higgin.)	1 foot in 29,400 years. (Calculated from Mr. Higgin's estimate.)
Mississippi	618,000 (By Messrs. Humphreys and Abbot.)	7,474,000,000 (By Messrs. Humphreys and Abbot.)	1 foot in 6,000 years. (By Mr. Croll.)
Danube	300,321	1,255,500,000 (By Mr. Ch. Hartley.)	1 foot in 6,846 years.
Shat-el-Arab	295,461	—	—
Ganges, at Ghazpoor	203,485 (By the Rev. Mr. Everest.)	6,368,000,000 (By the Rev. Mr. Everest.)	1 foot in 2,358 years.
Indus	199,476	—	—
Atrato	185,274	—	—
Nile	130,032	—	—
Yellow River	116,000 (By Sir George Staunton.)	17,520,000,000 (By Sir George Staunton.)	1 foot in 1,464 years.
Rhone	91,935	594,000,000	1 foot in 1,528 years.
Rhine	69,741	—	—
Po	61,263	405,420,000 (By M. Lombardini.)	1 foot in 729 years.
Pei-ho	7,755 (By myself.)	80,000,000 (By myself.)	1 foot in 25,218 years.
Thames, at Kingston	2,300 (By Prof. Prestwich.)	1,865,900 (Huxley's "Physiography.")	1 foot in 9,600 years.† (Huxley's "Physiography.")

* Where not otherwise mentioned I have obtained my information of the discharge of water and sediment from the "Earth," by Elisee Reclus.

† This estimate also includes the solids held in solution.

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We have now the necessary "data" for considering these three rivers in their conjoint character. Together they drain an area of 1,105,000 square miles; they discharge a body of water equal to 894,000 cubic feet every second; and they carry down every year to the sea 24,028,800,000* cubic feet of sediment, which represents a rate of subaerial denudation equal to the removal of one foot of solid rock in 1,687 years.

If we look upon the Yang-tse, the Yellow River, and the Pei-ho as laboring, with the assistance of the gradual elevation of the sea border, which is at present going on, to extend the territory of China seaward towards her ancient coast-line—represented by a line running from Kamtschatka through the Kurile Islands, Japan, the Loo-choo group, Formosa, down to the Malay Archipelago; † and carry ourselves forward into the future when such task is completed and the waves of the Pacific beat once more against this old sea border, we shall not have much difficulty in picturing to ourselves what will then be the state of matters. In the place of the gulf of Pe-chili and the Yellow Sea there will be vast alluvial plains traversed by the waters of the Yang-tse, the Yellow River, and the Pei-ho; but before the ancient coast line is reached they will have joined to form one great river and one united delta. If the Yellow River confines itself mostly in future ages to its course into the gulf of Pe-chili, that gulf will be filled up in process of time; and the Hoang-ho winding along through the bed of this obliterated sea will, after being joined by the Pei-ho, turn its course southward, deflected by the Corean peninsula, until it meets at length its sister stream. On the other hand, should the Yellow River be mostly occupied in future in advancing its southern delta it will join the Yang-tse at a period much less remote from the present; and their united waters will pursue an easterly direction subsequently to be joined by the Pei-ho, which will have been gradually finding its way through the gulf of Pe-chili and the Yellow Sea during the preceding ages. In either event the union of these three rivers would follow.

Such being the case, it may be interesting to speculate on the time required by these rivers to fill up the seas into which they discharge their sediment. Sir George Staunton estimated that at the rate the Hoang-ho was discharging sediment it would fill up the Yellow Sea and the gulfs of Pe-chili and Lian Tung in 24,000 years; but M. Elisée Reclus is of opinion that this estimate ought to be doubled, as the Yellow Sea is much deeper than Sir George Staunton stated it to be (20 fathoms). On carefully examining the latest charts of these seas I am inclined to consider that this estimate cannot be assailed on this point, as my own determination of the average depth is 22 fathoms.

We will now attempt to gauge the the time that the three rivers in question would require to fill up, by the sediment they deposit the portion of the sea which is included by the gulfs of Pe-chili and Lian Tung, the Yellow Sea, and the Eastern Sea north of the 29th parallel and west of the 126th meridian. I have placed the total surface area at 200,000 English square miles, and the average depth at 26 fathoms; and following Sir George Staunton's mode of estimation I find that it would take sixty-six days to form an island a mile square reaching up to the surface of the sea. At this rate it would require 36,000 years to form all the sea in question into dry land, supposing of course that there was no elevation or depression of the sea-bottom during that period. But the recent formation of several islands and shoals in the Yang-tse estuary, the occurrence of raised beaches and marine remains at Hang-chau, Wusung, and Chefoo, with other similar evidences, demonstrate that there is an elevation of the coast going on at present; and, in that case, it will require considerably less than 36,000 years to form the sea into *terra firma*.

Perhaps Sir George Staunton's original estimate for the Yellow River may not be far wrong when applied to the whole sea in question.

* In "Page's Advanced Text-book of Geology," Staunton's estimate of the sediment discharged by the Yellow River has been erroneously applied to all "the great Chinese rivers."

† Vide a paper on this subject, by Mr. A. S. Bickmore, read before the North China branch of the Asiatic Society in November, 1867.

In Western Australia the construction of a telegraph line to Roeburne is under consideration.

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THE PRINCIPLES INVOLVED IN THE CONSTRUCTION OF THE TELESCOPE.

By THOMAS NOLAN, B. S.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

I

The Telescope is certainly one of the noblest monuments of human genius, and its invention will always be considered as among the most remarkable in the whole circle of human knowledge. It is a work, in which, by following unconsciously the plan of nature in the formation of the eye, we have come the nearest to the construction of a new organ of sense, and by means of which, we have extended our views and researches far beyond the limits of our own globe—that sphere which nature seemed to have designed for our inquiries. Enabling us to penetrate into the immensity of space, and to become, as it were, familiar with other worlds placed at almost immeasurable distances from us, the telescope has revealed an infinitude of celestial bodies, whose existence must forever have remained unknown to us, but for its invention. Its history, like that of every complicated instrument, has been a history of improvements. The question of the origin of the invention, although abundantly inquired into, has never met with a satisfactory answer; and the question—who made the first telescope? will probably never be conclusively settled. For the invention, in its original form, we are indebted to accident, or to the trials of men who had little knowledge of the principles of the science upon which they were conferring so great a favor. Not a single thing, but a combination of things, the telescope in its earliest forms was a simple combination of certain kinds of convex and concave lenses, known and used as spectacles many years before; and whether the credit of the invention should be given to Metius, Lipperhey, Jansen, Baptista Porta, Galileo, or to others whose names are unknown, it is a most difficult and invidious task to decide. But interesting though these inquiries may be, it is not my purpose in this dissertation to enter into the discussion of the question as to who was the inventor of the first "optick-tube," or to describe minutely and historically all the several successive changes and improvements which it has undergone in the hands of different philosophers; but rather, to examine the theory of those forms of refracting and reflecting telescopes which have been of more general application.

THE OPTICAL PRINCIPLES INVOLVED IN THE CONSTRUCTION OF THE TELESCOPE.

A telescope, in general, consists of a tube containing a system of glass lenses, or a speculum in combination with such lenses; and is used to render distant objects more clearly visible; (1) by enlarging their apparent angular dimensions, and (2) by introducing into the eye a superior quantity of their light.

Those constructed with glass lenses only, are called dioptric or refracting, and the others catoptric or reflecting telescopes. In the refracting telescope, rays of light coming from the object are made to converge by a convex lens, and, if not intercepted, form an image at its focus. In the reflecting telescope, the image is formed by the reflection of the rays which impinge upon upon the concave surface of a speculum.

We will first consider,

I. THE SIMPLE REFRACTING TELESCOPE.

In exhibiting the principles on which the refracting telescope is constructed, we must first explain the formation of the image of an object at the focus of a lens.

When a convex lens is placed before an object, an image of the latter is formed at a certain distance behind or before the refracting surface, whose magnitude is greater or less, according as it is formed farther from, or nearer to the

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surface. The one particular distance at which the image is distinct, is called the focus. At every other distance it is hazy and confused. By the use of the telescope the image is produced on the retina of the eye itself, and its office is to prepare the rays of light for forming on the retina an image larger and clearer than would be formed without its help.

In (Fig. 1) two rays proceeding from the top and bottom of the object AB are represented separately. The ray A*a*, passing through the center of the lens O, is unaffected, because the surfaces through which it passes are parallel to each other, and from the property of the lens, all other rays from A, on passing through it, are brought to a focus somewhere on A*a*, depending upon the curvature of the lens. In like manner, all rays from B are brought to a focus at *b*, each point of AB having its corresponding focus in *ab*. The latter is smaller than AB in proportion as *c*O is less than CO; and if we increase the focal length of O till *ab* is twice the distance away, it becomes double its present size. The place of an image depends upon the distance of an object, and when the latter is considered at an infinite distance, as is the case with the heavenly bodies, the image is formed at the principal focus of the lens, or the focus of parallel ray.

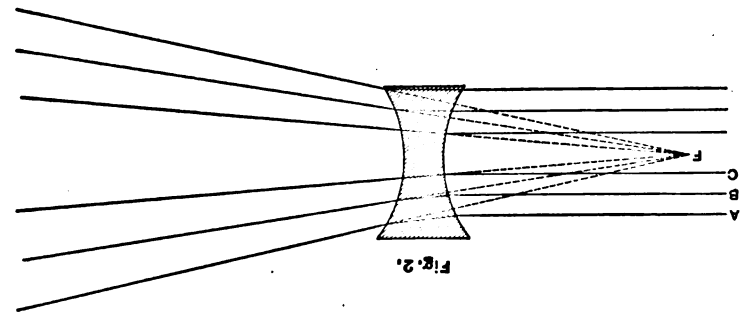

Fig. 2.

If rays ABC &c., pass through a concave lens, as in (Fig. 2), they are not brought to a focus, but diverge as if they came from some point F, called the virtual focus.

The first condition which a telescope must fulfill is, that it shall so dispose all rays emanating from any point in an object, that they may emerge from the instrument parallel to each other, in the usual or medium situation of the mechanism.

The second condition is, that the mechanism itself shall be adjustable, so as, by a movement of the parts *inter se*, to convert this parallelism into a slight divergence or convergence, to suit the eyes of near or long-sighted persons.

The third condition is, that the pencils of parallel rays coming iuto the eye from different points of the object, shall be inclined to each other at greater angles than those actually subtended at the eye, by the respective intervals between the points themselves. The number expressing this ratio is the measure of the *magnifying power* of the telescope, and the *apparent linear dimensions* of an object being in proportion to its magnifying power, the apparent enlargement of its *superficial area* is as the square of the magnifying power.

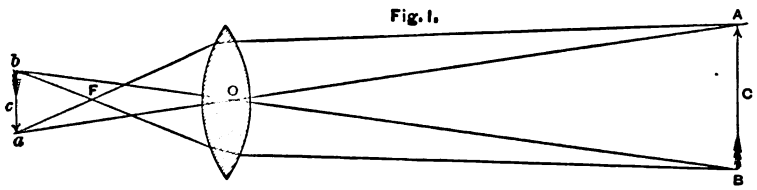

Fig. 1.

The simplest construction of the refracting telescope is that in which the image formed in the focus of a convex lens, or *object-glass*, is viewed through a second lens, or *eye-glass*, so placed as to have the image in its focus for parallel rays incident in the contrary direction,

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and its axis coincident with that of the first lens.

Three cases arise by applying this principle, which afford telescopes of different characters:

1. The *Galilean telescope*, with double concave eye-glass, showing objects erect.

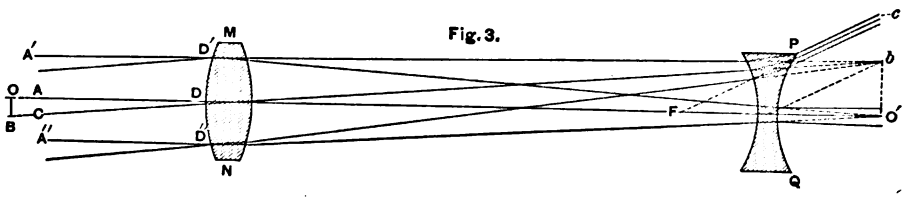
2. The *Astronomical telescope*, first suggested by Kepler, with double convex eye-glass, showing objects inverted.

3. The *Terrestrial telescope*, suggested by Rheita, with three double convex eye-glasses, showing objects erect.

pupil is small, and since it involuntarily contracts in proportion to the quantity of light impinging upon the eye, the field of view is so much the less as the focus of PQ is greater.

(3.) Since the nature of light will not admit of an eye-glass whose focus is diminished beyond a certain limit, and since the focus ought to be longer in proportion to the length of the focus of the object-glass, the field of view will be less the greater the length of the instrument, which inconvenience, together

Fig. 3.



1. THE GALILEAN TELESCOPE.

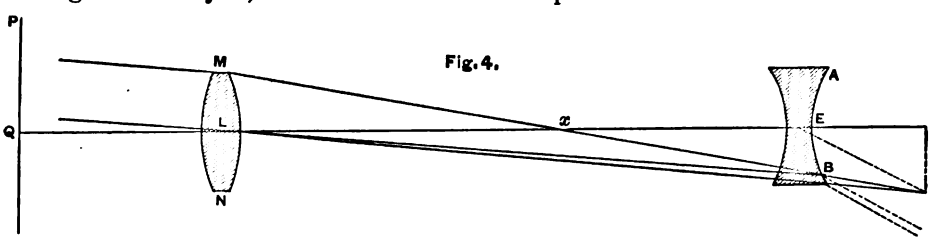
In this instrument, the eye-glass PQ (Fig. 3) is placed between the object-glass MN and its focus O′, so that the axes of both glasses are in the same line AO′, and their foci in the same point O′.

(1.) The object OB being supposed infinitely distant, incident parallel rays, as AD, A′D′, A″D″, are first rendered converging towards O′ by MN, and afterwards parallel by PQ. They are also much denser than before their first refraction, and, when received by the eye, paint an image of the object, so much the more

with those above described, render this instrument almost useless for purposes of astronomical observation.

(4.) The pencil of rays *c*, from B, under the axis, meets the eye in the direction *c*F, answering to a point also below the axis; and in the same manner, a ray issuing from any point of the object, above the axis, has a similar direction on emerging from the eye-glass. Consequently, objects and their images have like positions with respect to direction, when viewed through a telescope of this construction.

Fig. 4.



vivid, as the density of the pencil of rays is then greater than before it fell upon MN.

(2.) The point B sends forth parallel rays as CD and its two parallels, which are refracted towards some point *b*, and then rendered parallel by PQ. Since this pencil, in emerging from PQ, diverges from that formed by the point O, a greater number of the parts of the object will be seen as the eye is placed nearer to PQ, and as the pupil is more dilated. But since the dilation of the

(5.) To determine the field of view, we let MN (Fig. 4) be the diameter of the object-glass, AB that of the pupil of the eye whose center is in the axis of the telescope, and join M and B, the opposite extremities of these diameters, and let MB meet the axis in *x*, and the image in *p*. We draw also LB and L*p*, and suppose *p*L and *q*L to be produced till they meet the object in P and Q. PM is refracted to the pupil in the direction MB, but every other ray in the pencil, as PL, and every ray which

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comes from a point more distant from the axis, falls below the pupil. Therefore, PQ is half the linear magnitude of the greatest visible area. QP is measured by the angle QLP, or by its equal qLp.

$qLp = ELB + BLp$, and

$$BLp = LBM - LpM.$$

$$\therefore\ qLp = ELB + LBM - LpM.$$

And 2QP is measured by

$$2ELB + 2LBM - 2LpM.$$

That is, the linear magnitude of the field of view is measured by the angle which the diameter of the pupil subtends at the center of the object-glass, increased by the difference between the angles which the diameter of the object-glass subtends at the pupil and at the image.

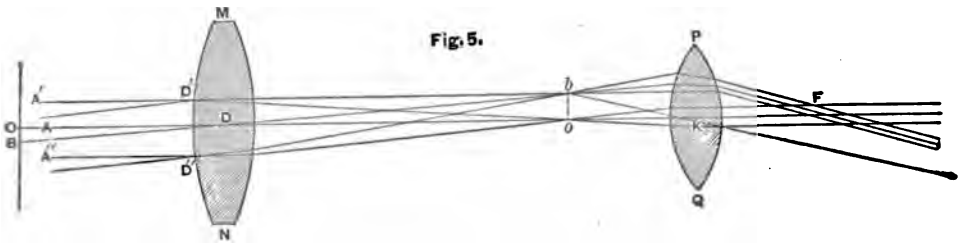
2. THE "ASTRONOMICAL" TELESCOPE.

This instrument, represented in (Fig. 5) differs from the Galilean, in having a convex instead of a concave eye-lens, which is so placed with regard to the object-glass that their foci coincide in the axis of the telescope between the two glasses, instead of being beyond the eye-glass as in the Galilean telescope. PQ is the eye-glass, MN the object-glass, KD the axis, and o the common focus.

(1.) The rays AD, A′D′, A″D″ from O in the object OB, infinitely distant, are refracted to the focus o where they form an image of O.

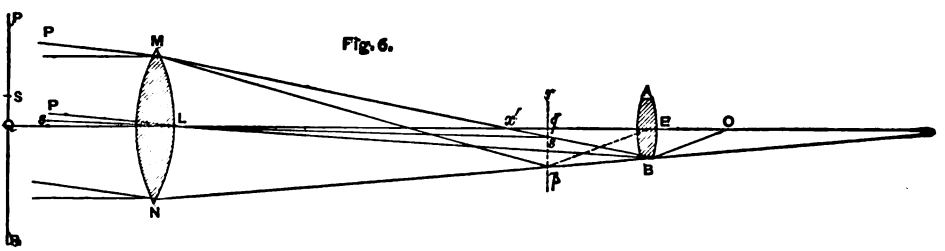
(2.) This image o is considered as an object placed in the focus PQ, and rays diverging from o, and falling on PQ emerge parallel to each other, and are so much the more dense as the focal length of PQ is less than that of MN. They therefore paint on the retina a new image of O, which is so much the more vivid, as the surface of MN is greater—that is, as it admits a greater quantity of light.

(3.) Rays from B form in b, an image of this point, and falling afterwards on PQ, emerge parallel and more inclined to



AF as the curvature of PQ is greater; so that the axis of the pencil which they form, cuts the common axis of the two lenses in F, the focus of PQ. Consequently, to see all of ob at the same time, the eye must be placed at F, the common intersection of all rays emitted from each point of ob, or of OB.

(4.) b, the image of B, is refracted to the eye in the direction PF, and has a different direction from that in which it is emitted from B; and the ray which renders visible a point above the axis reaches the eye as if it proceeded from below the axis; and thus the entire image is reversed.



(5.) To find the field of view, we let MN (Fig. 6) be the diameter of the object-glass, AB that of the eye-glass, and draw NB, letting it cut the image pqr in p. We draw also pL, and conceive pL and EL to be produced until they meet the object in P and Q; and draw pE and NP, and also BO parallel to pE. Then the eye at O receives the ray NBO, which comes from a point in the object at

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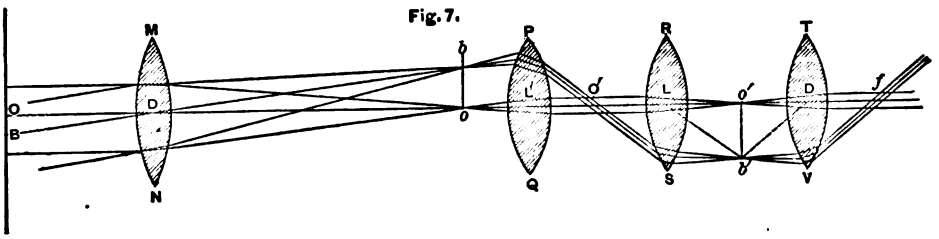
the greatest visible distance from the axis of the telescope. For rays from any point above P, converge to a point below p, and fall below AB; consequently P is the exteme visible point in the object, and QP is half the linear magnitude of the visible area.

(6.) To find the *brightest area*, we draw MB cutting pqr in s, and the axis LE in x', and draw Ls, and conceive it produced till it meet the object in S. Then, (a) if x'E be greater than qE, all rays from S falling upon MN, are refracted to AB; for, SM is refracted in the direction MsB, and any other ray of the pencil, as SL, crosses MB at s, and falls somewhere between A and B. In like manner, rays from any point between S and Q, are refracted to AB. (b) If x and q coincide, the brightness of the field increases to the center. (c) If q *fall between* L and x', all the rays belonging to any one pencil incident upon MN, are not received by AB.

Fig. 7.



3. THE TERRESTRIAL TELESCOPE.

The nature of this construction is easily comprehended by reference to (Fig. 7). The four lenses have one common axis A f. and each contiguous two are so situated that their foci coincide. If OB be an infinitely distant object, the parallel rays from O, in the axis produced, from an image in the focus o, whence, falling on, PQ they emerge parallel to each other and to the axis. Falling upon RS, they are refracted to the focus o', where a second image is formed, and then diverging, and falling on TV, they are refracted to the eye in directions parallel to the axis. In like manner, rays from B form in b an image of that point, whence, falling in PQ they are rendered parallel to each other, but oblique to the axis till they meet RS, by which they refracted to the second focus b'; whence, falling on TV, they are again rendered parallel to each other, but so inclined to the axis as to meet it again with all the other rays in the focus f, where the eye is placed to receive the final impression, which is that of an image corresponding, as to its direction, with the object itself. For the ray b'Vf, which carries the image of the point B, has a similar direction with respect to the axis, as the ray proceeding immediately from B.

As the properties of this instrument are analogous to those of the astronomical telescope, it is unnecessary to enter into further discussion of the principles of its construction.

FILTRATION THROUGH SPONGY IRON.

From "Engineering."

It is now some years since Mr. Gustav Bischof demonstrated the remarkable properties of spongy iron as a filtering material for the purification of water for drinking purposes, and spongy iron filters are already in extensive use for domestic purposes. Notwithstanding this, however, and notwithstanding also the testimony to the powers of spongy iron which has been afforded in the sixth report of the Royal Commission on Rivers Pollution, in the reports of the Registrar General, in the Army Medical Report for 1877, and elsewhere, the material has not yet been employed on a large scale for the filtration of water at any of our water works, a fact which is to be regretted when the remarkable effect of the material on Thames water is taken into consideration.

Although, however, spongy iron has not yet been introduced at water works

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in this country, it is, we understand, about to be employed by Messrs. Easton and Anderson for the filters at the Antwerp Water Works, which they are now in course of construction. To determine the suitability of the spongy iron for effectually dealing with the Nethe water which is to be used for the supply of Antwerp, Messrs. Easton and Anderson have recently carried out a series of experiments on a considerable scale, and these have yielded results of much interest. The arrangement employed consisted of two cast-iron tanks, each having a horizontal area of 342 square feet, while the one was about 11 ft. and the other 7½ ft. in depth. In the larger tank there was placed on a suitably constructed brick bottom, a depth of 3 ft. of spongy iron and gravel mixed in the proportion of 1 to 3, while above this was placed a bed of Harwich sand 18 in. in thickness. From the bottom of this filtering tank, the water was drawn off to the second tank, this latter containing, as filtering material, a bed of gravel about a foot thick with 2 ft. of Harwich sand above.

The object of the second filter is as follows: In passing through the spongy iron a small quantity of iron is dissolved in the form of protoxide, and if not removed it would, when converted into peroxide by the contact of the water with the air, be thrown down in the form of a brownish deposit. In the spongy iron filters for domestic use the further oxidation of the protoxide is effected by an admixture of manganese binoxide, the peroxide of iron being thus formed and retained in the filtering material. This use of the manganese binoxide would not be convenient on a large scale, and in the arrangement we are describing the water after passing through the spongy iron in the first tank is allowed to come in contact with the air in the second tank, when the peroxide of iron is thrown down and arrested by the filtering material which that tank contains, thus allowing the water to be delivered perfectly clear.

With the arrangement we have described, Messrs. Easton and Anderson found that they could efficiently filter the Nethe water at the rate of 150 gallons per square foot of filtering surface per 24 hours, or 6¼ gallons per square foot per hour. At the Metropolitan Water Works the rate of filtration with the ordinary filter beds varies from about 1⅛ gallons per square foot per hour in the case of the East London and the West Middlesex Works to as much as 4 gallons in the case of the Lambeth Works, but the average rate for all the works is decidedly under 2 gallons per square foot per hour, so that the results which Messrs. Easton and Anderson have obtained with spongy iron, and with a water greatly in need of filtration, point to the possibility of employing filter beds very materially smaller than those ordinarily necessary.

So far as experience at present goes, the spongy iron in filters requires no renewal. Its action appears to be to produce an oxidation of the organic matters in the waters traversing it, the result being a discharge from time to time of carbonic-dioxide. We have referred to the testimony of the Registrar General to the effect of spongy iron, and we cannot do better than quote from his report for 1877 the following paragraph respecting it. He says: "The Thames was in high flood during nearly the whole of December, and its water was loaded with organic impurities of the most disgusting origin. It may be interesting to those who can afford the cost of domestic filters, to know that even this polluted water can be *chemically* purified by filtration through spongy iron. I have inserted in the analytical table, for the purpose of comparison, the results yielded by the Grand Junction Company's water, after passing through a spongy iron filter, which had been in use for more than a year. The filter removed nearly nine-tenths of the organic matter, and more than one-half of the hardness from the water." The table here referred to is annexed, the quantities being given in parts per 100,000.

The manufacture of spongy iron on a large scale is an interesting process, and we may hereafter have something to say concerning it. Meanwhile, however, we may state that Mr. Bischof has taken Dr. Siemens' well-known experimental works at Towcaster, and is making spongy iron there in the Siemens revolving furnace, which has proved admirably adapted for the purpose. Considering the results which have been gained with domestic filters, and the promising data

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Description of Samples.	Temperature C.	Total Solid Impurity.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates and Nitrites.	Total Combined Nitrogen.	Previous Sewage or Animal Contamination.	Chlorine.	Hardness.
Water supplied by Grand Junction Company.....	9.7	28.36	.380	.074	.001	.265	.340	2340	1.65	18.0
Same after filtration through spongy iron....	..	14.70	.038	.012	.010	.128	.148	1040	1.70	8.1
Supply of the Kent Company.....	13.5	37.50	.048	.012	0	.368	.380	3360	2.30	25.5

afforded by Messrs. Easton and Anderson's experiments at Antwerp, the application of the system of spongy iron filtration at the Antwerp Water Works will be watched with much interest, and we hope in due time to be able to place full information regarding the results before our readers.

WEIGHT IN LOCOMOTIVE CONSTRUCTION.

From "The Engineer."

THE "Links in the History of the Locomotive," which we publish from time to time as we succeed in picking them up, even if worked into a continuous chain, extending from 1829 to 1880, would be complete only for a day or a month. At the end of some such period a new type of engine would be built, and a new link would have to be added to the chain. Put in another way it may be stated that locomotive engine construction is a thing of continual progress. It is difficult, indeed, to find any branch of mechanical engineering in which changes in design, and form, and proportion, so rapidly succeed each other. There is not a railway in the kingdom which is now worked by engines of precisely the same pattern as those in favor ten or even five years ago, and it is to be assumed that novel types are adopted not simply for the sake of change, but because some advantages are supposed to be gained. A glance at the direction which progress in locomotive construction is taking may not be found uninteresting.

The most prominent feature in the modern British locomotive of the most improved type is its great weight. English and Scotch locomotive superintendents have gone on year by year making their engines heavier and heavier, and we have no reason whatever to think that finality has been reached in this direction. Locomotives are not made heavier for the sake of securing adhesion alone, but in order to secure immunity from breaking down. In other words, they are made much stronger than they used to be. Thin boilers, and frame plates seven-eighths of an inch thick, have given place to $1\frac{1}{8}$ in. plates; cylinder castings are heavier, motion bars have increased dimensions, pins are made larger. In short, engines are made stronger all over than they were made a few years ago, and for the same reason they have risen from a maximum weight of 30 tons or thereabouts to a maximum of 36 tons, or even more. We speak now of tender engines. In tank engines the change is still more marked; up to about fifteen years ago a tank engine which weighed more than 30 tons was an exception. At the present moment there are bogie tank engines working the Tilbury and Southend Railway which we understand weigh 56 tons in running order. Mr. Kirtley's Crystal Palace tank engines weigh about 50 tons in working order, and various other examples of heavy engines could be cited. We may be excused, perhaps, if we digress here for a moment, to say that it is by no means easy either to escertain

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the weight of an engine in working order or the distribution of weight on the wheels. Locomotive superintendents do not always possess the means of weighing their engines as a whole, and they even less often can weigh them wheel by wheel. For this reason rather vague statements get into circulation, some of which are not quite true, while others may be true. We recently heard it asserted, for example, that 8ft. driving wheels of the single outside cylinder engines of the Great Northern Railway carry 19 tons or a little over now, or about four tons more than they did at first, as they were found to lack adhesion. The extra weight has been obtained, of course, by a readjustment of the springs. Whatever uncertainty may exist as to precise weights, there can, however, be no doubt that, as we have said, weight has, on the whole, augmented and is augmenting. Not a few experienced locomotive superintendents hold that we are in this respect progressing in the wrong direction, and that engines are now made heavier than they need be made, and that just as good results could be obtained from lighter machines. The question ought to admit of being readily settled. The modern engine is in many cases called upon to do more work and harder work than its predecessors. This may be granted; but it is by no means clear that it must be made heavier to enable it to do this additional duty. The adoption of steel rails opened up new possibilities to the locomotive designer, and he has not been slow to avail himself of his chances; but we may ask, what has really been gained in this way? Locomotive improvement means less first cost or less cost for repairs, or less cost for fuel or more hauling power. Is it certain that increased weight will entail any one of the advantages we have named? We think not. One man builds an engine with 17in. cylinders, 24in. stroke, and 1100ft. of heating surface, which weighs 28 tons; another man builds an engine with the same stroke and cylinder and heating surface, and it weighs 34 tons. Does it follow that the last must be the best engine of the two? We doubt it. The difference between them will probably be very small. They will both be four-coupled, one will have 6ft. and the other 6ft. 6in. drivers, perhaps, but the hauling power of both will be practically the same, and in the long run it will, we venture to think, be found that the light engine will not require more repairs than the heavier engine. It may seem a hard thing to say—and we say it with some reluctance—that the modern designers of locomotives do not manifest as much ingenuity of skill in scheming as those who have gone before them. The locomotive superintendents of to-day have an enormous stock of accumulated knowledge to draw upon, which was not possessed by the men of the last generation, and they have, besides, tools and materials of the highest perfection, and there are comparatively few demands made on their inventive powers. The best features in the modern locomotive are its simplicity and its workmanship. The display of a little more originality would, we have no doubt, materially improve the engine. The essence of success lies in putting weight into the right place, and in so disposing our materials that they may be loaded and worked to the best advantage. In this way a great deal of weight may be saved. Let us cite as an example of what we mean, the staying of fire-box crowns. The bridge stays for a fire box will weigh with studs, nuts, etc., 15 cwt. or 16 cwt. We have heard of cases in which they weighed 30 cwt. The weight of vertical sling stays, doing the same work much better, would not exceed 5 cwt. or 6 cwt.

It should by this time be well known that engines have to go into the shops for repairs to wearing surfaces more frequently than for any other cause. Axle brasses and axles are a fruitful source of trouble, and it is much to be regretted that all railway lines are not laid for a gauge of 5 ft. This would have given 3½ inches more space for bearings. Four bearings would have been improved, namely, the two crank pins and the two crank shaft journals. The two first could have each been made about 4¼ inches long instead of 3½ inches, and the latter could have been about 8 inches, or even a little more, instead of 7 inches. To get increased surface in these bearings should be the great aim of the engineers' life; if he can succeed he will keep his engines out of the sheds. Mr. Webb is apparently more fully impressed

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with the importance of this truth than any other engineer in Great Britain, and it is for this reason that Joy's valve gear promises to prove so valuable. There is much about Mr. Webb's practice of which we cannot approve, and he is content with a want of finish and style in his work which is not paralled on any great railway in Great Britain; but we willingly concede that he does not waste metal, and that he knows as well as any man living just what to put in a locomotive, and no engineer better understands what are the causes which send locomotives into the shops, and how best to deal with those causes. There is we fear a tendency among too many designers of locomotive engines to produce something which shall be grand and imposing, and this is accompanied by a certain degree of carlessness concerning the effect which an engine may produce on permanent way. Nor is there quite so much solicitude to keep down repair expenses as desirable. When everything has been made very big and very strong, and very heavy, the designer fancies he has done all that is needed; and if his engines make but 12,000 or 14,000 miles in the year he does not take himself to task; and yet had a little more care been taken to make the proper things big and nothing else, weight might have been kept down, first cost reduced, and the staying powers of the engine greatly increased. We hear every now and then of engines which have made their 90,000 miles or so without going into the shops for repairs. We heard only a few days since of an engine which had made 251,000 miles. If we examine them we shall find that the secret of their success lies in large bearing surfaces, efficient lubrication, and the disposition of metal in the proper place. We are writing now not for the experienced locomotive superintendent, who fully recognize the truth of what we are saying, and for whom indeed we speak, but for younger and less experienced men, and these cannot too strongly impress on their minds the truth that weight as weight is as a rule objectionable in a locomotive; and that it cannot be made to compensate for want of care and skill in proportioning the various parts of the whole machine to the discharge of the special duties to be porformed by each.

The augmentation in the weight of the modern British locomotive with which we have been dealing is due in same measure to the extended adoption of the bogie. It was originally invented in this country, and went thence to the United States. Here the earlier lines—like the Manchester and Liverpool, the London and Birmingham, and the Great Western —were nearly level and very straight. On such roads the bogie was a superfluity, augmenting weight and doing no good ; but in the United States matters were different. Their roads were bad, steep, and crooked ; rigid engines could not traverse them, and speeds were slow, so bogies carried the leading ends of the engines and balance beams the trailing ends. In process of time we began to make crooked and hilly roads, and it was found advisable to adopt the bogie, which is rapidly growing in favor in this country. It is now in use on the Midland, the North British, the Lancashire and Yorkshire, the Great Northern, the North-Eastern, the London, Chatham, and Dover, the London and Brighton, and many other important railways in Great Britain. Equalizing beams are not so much in favor. It is not easy to say why. Mr. D. K. Clark's dictum that they make an engine unsteady did much at one time to stop their adoption, and they have not since increased in favor. They are, however, in use on several lines. The London, Chatham, and Dover and the Metropolitan Railways may be cited as examples. The bogie is no doubt of value in saving permanent way, because it consolidates it and brings it to its bearings before the heavily loaded wheels reach any given spot ; but the bogie is by no means free from defects. It adds a good deal, as we have said, to the weight of a locomotive, and yet more to its first cost. It is a noteworthy circumstance, that as our railways departed from the original perfection given to them by such men as Brunel and Stephenson, and we have adopted the bogie, so in the United States, since track has been improved there a tendency has grown up to abandon the bogie and adopt the English system. The change has begun with cars. Experiments have been made which show that the resistance of bogies with a very short wheel base is much greater than that of bogies with

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the axles far apart; and four-wheeled goods wagons of the English type are now being tried on American lines, and we have very little doubt that locomotives without bogies will soon be built. Some of the Pullman cars are carried by bogies with six wheels in each, and a wheel base of about 15ft., and it is obvious that if these can get round the curves met with a locomotive properly designed and without any bogie can have no difficulty. It is also noteworthy that American engineers are following English practice in another respect, and are building locomotives with one pair of driving wheels only—a thing hitherto unheard of in the United States.

We have said that weight is objectionable in locomotives, and we feel that it is necessary before concluding to explain precisely what we mean, for so far as adhesion is concerned a locomotive cannot weigh too much, and the heavier it is the better. But the locomotive and the permanent way ought always to be regarded as parts of a whole; just as much one with each other as the table of a planing machine and the V grooves which carry it. As regards the rails, the lighter an engine can be made the better. Now, if the locomotive superintendent did all in his power to keep down weight, he could not get rid of it so far as to reduce the efficiency of a four-coupled engine. He might, it is true, diminish the hauling powers of a single engine; but as these have or ought to have in all cases large driving wheels, their power of pulling is never very great. Of the five or six tons unnecessary weight now and then put into an engine, only a portion reaches the driving wheels, and it will be generally found that a four-coupled engine which weighs more than 30 tons is very severe on the road, unless it has a bogie; nominally 30 tons means 5 tons a wheel, not too much for a steel rail; really it means 7 tons or even 8 tons per wheel on one pair of wheels, which is too much. In practice it will not be found, we repeat, practicable to make a four-coupled engine too light, but it will be very easy to make it too heavy by putting metal where it is not wanted. Every engine is too heavy which possesses more weight than just enough to enable it to perform its work with efficiency. Drivers, we know, like heavy engines, because they do not slip in bad weather; but a few pounds of sand will as a rule do the work of some tons of iron, and much better, and locomotive superintendents should not permit themselves to be too much guided by the utterances of their men. The American engineers first taught us the real value of sand, and Mr. Adams, when on the North London Railway, showed us how to use it. A little consideration should be shown for permanent way. Working expenses have of late been increasing on all our railways, and it is worth considering whether some of this augmentation may not be due to the growing use of heavier and heavier engines. It may be that the demands of traffic are so importunate that they cannot be dispensed with, yet the running of 20 or 25 ton locomotives over 75 lb. steel rails presents a tempting picture. Such a road under such engines, once made, ought to last almost for ever; we cannot have 20 ton engines, but the nearer we can keep to that weight the better for the road and the shareholders.

BRICKS AND THEIR HISTORICAL INTEREST.

From "The Builder."

In the antiquity of the brick as a building material it is needless, nor is it indeed our intention, to insist. The great national collections of Europe, the British Museum foremost in the number, show us bricks, sun dried and baked, from the ruins of Nineveh, and from the days of that city to the present moment bricks have never ceased to be an important instrument in the hands of the builder. That throughout Asia Minor they were largely employed we have seen, only very recently, proved in these columns; M. Rayet, in his work on Miletus, having shown that the far-famed palace of Crœsus was built of no more costly materials than honest bricks. What those bricks were, and their quality, are even

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to this day appreciated by the natives, who for many centuries, have plundered the ruins to build or to patch up their own even more ruinous houses. The use of bricks among the Romans, who largely employed them as building materials, as we see in the familiar instance of the Temple of Concord, has been more than once the subject of the inquiry of industrious antiquaries, for the Romans were not content with producing the flat, tile-like brick which is so often to be met with in the lower portions of antique structures scattered over the Empire, and that are known in England, but their bricks were indelibly stamped with the mark of their maker, the names of the reigning consuls, and sometimes the year. From this source, then, more than one patient archæologist has gathered a rich store of information. But few inquirers have ventured far on the apparently arid and difficult road, which has hence remained little explored. Some curious information has, however, been lately thrown on the question by the researches of a French antiquary, M. Descemet, who has published in a recent number of the *Bibliothèque des écoles d' Athènes et de Rome*—an excellent publication, founded in 1877 and now at its seventeenth number—an article on the "Inscriptions doliaires latines" or Roman brick-marks, more especially relative to the *gens Domitia*, in antique Rome the most renowned brick-makers.

From an epigraphical point of view the brick marks of the Romans have aroused the attention of more than one archæologist, but the difficulties which have stood in the way of procuring the stamps, added to the enigmatical nature of the inscriptions themselves, have led the inquirers to fields where the results were more showy and more easily obtained. M. Descemet has long been known to the antiquarian world; as far back as 1857 his "Fouilles de St. Sabina" attracted no little attention, as also, in 1876, his study, "Sur quelques Regles de Briques antiques," published in the *Bulletin de Correspondence Archæologique*. In possession of a valuable collection of stamps of his own, together with copies from the brick stamps of the Vatican Museum, M. Descemet had at his disposition more than ordinary sources of reference, and the result of his study has been the work the title of which is above given.

The Italian antiquaries of the seventeenth and eighteenth centuries, Nardini, Ciampini, and their contemporaries, had not largely drawn on the store of historical information afforded by the Latin brick inscriptions; Fabretti was, indeed, the first to set into any order the more remarkable of these, but his efforts were merely tentable; his collection of inscriptions was unclassified and incomplete. It was reserved to the worthy Abate Gaetano Marini, the curator of the Vatican Museum at the close of the last century, to put together in a methodical manner the stamped bricks of the choice collection under his control; this task he admirably performed, preparing a learned catalogue which however remained at his death in an incomplete and manuscript form; but, such as it is, this manuscript preserved in the Vatican Library, has proved a mine of information to all subsequent writers. Marini's catalogue was arranged with admirable order and carefully classified, each brick of the collection being the subject of numerous commentaries.

In spite of Marini's method, M. Descemet has adopted another system more suited to the requirements of the day, as rendered necessary by the considerable additions made to the list of brick inscriptions since the recent excavations. In his introduction, M. Descemet has carefully shown the importance of the study of these brick inscriptions, by which the date of the erection of a building may be approximately ascertained. But as the author hastens to add, the fact of bricks bearing dates, or stamps being found in certain spots, is not, of course, conclusive evidence to the archæologist. Thus, in 1844, at Aix, in Provence, a brick of the year 123 was found, stamped with the mark of a Roman workshop, but the presence of this brick can alone be accounted for by the effect of accident, as it was scarcely possible that a town near Marseilles, so long famous for its pottery, should receive its bricks from Rome. On the shores of the Adriatic, at Pola and Zara, and in other towns of Istria and Dalmatia, the existence of a large number of bricks bearing the stamp of Rimini would tend to show that the brick trade, which still exists on

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both sides of the Adriatic, can be traced back at least eighteen centuries.

But apart from the geographical information these stamped bricks afford, the inscriptions they bear throw not a little light on an ill-known state of Roman society—the education of the slaves, who though we have classic evidence proving that they were placed under schoolmasters, would seem to have little profited by this education, as the inscriptions it was their duty to stamp could only have had their letters placed upside down or transposed (as they are often found) by persons unable to read, who copied as well as they could a model under their eyes.

How these stamps and brick inscriptions were made is a point of some uncertainty. Had the ancients moulds, or did they use movable types? This latter method would suppose a great invention of the fifteenth century to have been forestalled. M. Descemet, who devotes some pages to the discussion of the question, concludes in favor of the mould, such as we see examples of in more than one national collection. The stamp was cut in relief, or incised, and then—like the butter-print of the present day—made use of. As for the character of the spelling to be met with, this would naturally arise from the want of education of the workman.

Among the various other points considered by M. Descemet, the reason why the Roman bricks bear the date of their production is not the least curious; but when Pliny's advice to the architect is remembered, only to make use of bricks when two years old—"*ædificiis nonnisi bimos probant*,"—an explanation may, perhaps, be found. A point has been omitted by M. Descemet—one to which attention is drawn in a recent able article in the *Revue des Questions Historiques*—in his neglecting to refer to the palms, pine cones, and animals so often found stamped on the Roman bricks. It is now known that with the potters whose name represented or recalled any object or animal, this object he stamped on the pottery or brick of his make. Thus, where we meet with the stamped image of a wolf we may be sure that the workman's name was Lupus.

As the title of the work shows, it is alone to the brick inscriptions relative to the *gens Domitia* that attention has been paid. Why this *gens* has been chosen the author explains. It would appear that the *gens Domitia* possessed the largest and most important of the brick manufactories of ancient Rome. Apart from this, the *gens* take no mean place in the history of Rome; in the person of the virtuous Marcus Aurelius, it ascended the imperial throne. From the brick inscriptions gathered, the wealth of the emperor would appear to have been enormous, as we learn by the large number of workshops his *gens* employed, in company with those of the *gens Aria* which he inherited through his marriage with Faustina.

The interest of this quiet and apparently little-inviting study would be thus seen to be great. Its historical value is no less appreciable. We are comparatively far from the days when the history of ancient times was merely gathered from former texts; the aid afforded by numismatics and epigraphy is largely called into requisition by the more serious modern historians. This little work of M. Descemet shows us how, even from the humble sources of the brick inscriptions, important facts may be gathered. The careful and beautifully cut Roman stone inscriptions, so easy to read, are not sufficient; the research can be carried further, as we see for instance, in the study by M. Mumont on the ceramic inscriptions of Greece, and even more strikingly in the delightful study which M. Dressel published some time since on the shattered *débris* of Monte Testaccio. M. Descemet's inquiry into the brick-marks of ancient Rome has already yielded some curious information; it is to be hoped that his success will encourage him to further study in this yet far from exhausted field of archæological research.

The invention of binocular glasses has usually been attributed to Father de Rheita, who died at Ravenna in 1660. A printed placard has lately, however, been discovered in the Biblotheque by Signor Govi, which indicates that the credit of the invention is due to one D. Chorez, who lived at the sign of the "Compass" on the island of Notre-Dame, and who made the "lunettes" in 1625.

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AN INSTRUMENT FOR GAUGING THE FLOW OF STREAMS.

By M. DE PERRODIL.

From the "Abstracts" of the Institution of Civil Engineers.

THIS instrument, which is called a hydro-dynamometer, measures the velocity of a current by means of the torsion produced on a wire by the pressure of the water against a disc fastened to the end of the wire.

A narrow frame, resembling in form the longitudinal section of a tube terminating in a bulb at the top, is immersed vertically in the water, and turns, near its upper extremity, on a vertical pivot at the end of the horizontal bar which encircles, at its other end, an upright pole driven into the bed of the stream. A little, short, hollow cylinder, fastened to the under side of the bar exactly below the pivot, receives the end of the vertical wire, which can be secured by a screw. The wire, which is situated in the axis of the frame, passes through the center of the horizontal graduated circle, fastened, above the water-level, across the widest part of the frame, and is secured to the bottom cross-stay of the frame. A needle, fastened to the wire just above the graduated circle, serves to measure the torsion of the wire. A disc, placed in the same plane as the frame, projects from the end of a horizontal arm fastened to the bottom of the frame.

The instrument having been fixed with the disc at the desired depth, and on the up-stream side of the post, the disc assumesa position paralled to the current between the frame and the post, the needle and the frame are in the same plane, and the needle at the zero of the circle. On turning the needle by hand a torsion is produced on the wire, and the frame and disc may be thus made to assume a position perpendicular to the current. As the needle oscillates inconveniently, owing to variations in the velocity of the current, the wire is secured at the top by the screw as soon as the frame and disk are exactly perpendicular to the current, and the needle being fixed, the observer is free to note the oscillations of the graduated circle, and can read off the mean angle of torsion, which is independent of friction.

The velocity of the current is obtained by the equation $v = c\sqrt{a}$; where a is the angle of the torsion, and the value of c can be determined, either approximately from the coefficient of torsion of the material, or actually by experiment. The Author determined by experiment the value of c for the three different-sized discs he employed. The instrument was placed under one end of a small footbridge revolving round a central axis, and it moved in an annular trough, 2 feet wide, containing water. By turning the footbridge, any desired velocity could be imparted to the instrument, and the motion was so regulated as to keep the angle of torsion constant. The motion imparted to the water by the instrument passing through it was also observed, so that the actual velocity of the instrument through the water might be accurately ascertained.

A brass wire, $6\frac{1}{2}$ feet long and $\frac{1}{8}$ inch in diameter, was employed. A disc with a radius of $2\frac{1}{2}$ inches was used for velocities not exceeding 1 foot 4 inches per second, with a radius of $1\frac{1}{4}$ inch for velocities between $1\frac{1}{8}$ and $3\frac{1}{4}$ feet per second, and with a radius of $\frac{5}{8}$ inch for velocities between $3\frac{1}{4}$ and 10 feet per second. The distances in these three cases between the center of the wire and the centre of the disc were respectively 8 inches, 4 inches, and 2 inches. The Author considers Woltmann's hydrometric mill inferior to his instrument, as errors may occur in registering the number of turns of the mill, and also in marking the time, and as it has to be drawn out of the water to be read. Also the true equation for deducing the velocity from the results of observations with Woltmann's mill has not been thoroughly agreed upon, M. Chasles considering it to be an equation to a straight line, and Herr Baumgarten an equation to a parabola; but experiments conducted by the Author, and recorded in the last article, confirm the correctness of M. Chasles' view. A superiority is claimed for the instrument over Pitot's tube, on

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account of its indicating the mean velocity with greater accuracy. Morever, the instrument actually employed can indicate a velocity of $\frac{3}{8}$ inch per second; whereas Woltmann's mill ceases to revolve in a current whose velocity is reduced to 4 inches per second, and a Pitot's tube is even less suited to measure accurately low velocities.—*Annales des Ponts et Chaussées.*

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS. The last issue of Transactions contains the following papers:

No. 205. The location of the Chimbote Tunnels, by O. F. Nichols.
" 206. Practical Consequences of Variation of the Wet Section of Rivers under General and Special Conditions, by Robt. E. McMather.
" 207. Wind Pressure against Bridges, by Ashbel Welch.
" 208. Cheap Transportation versus Rapid Transit and Delivery, by Martin Coryell.
" 209. The Crippling Strength of Wrought-Iron Columns, by C. L. Gates.

ENGINEERS' CLUB OF PHILADELPHIA.—The latest number of Proceedings contains:—

I. The Light-House System of the Delaware River, from the Head of the Bay to Philadelphia. By EDWARD PARRISH.
II. Rock Drills. By FRANCIS L. MILLER.
III. A Machine for the Solution of the Equation of the NTH Degree. By F. T. FREELAND.
IV. The Mexico and Vera Cruz Railroad. By COLEMAN SELLERS, JR.
V. Quantitative Determination of Combined Carbon in Cast Iron and Steel. By DAVID TOWNSEND.
VI. The Future Sewerage Requirements of the City of Philadelphia. By RUDOLPH HERING.

IRON AND STEEL NOTES.

WELDING CAST STEEL.—Two points must be taken into consideration chiefly in effecting the welding of steel: It is necessary to render the film of oxidized iron on the surfaces to be united by welding as fluid as possible, and some means must be found to restore to the steel the carbon eliminated during the process of heating to the welding temperature. According to the *Revue Industrielle*, M. Rust considers boric acid the most effectual in performing the former, and ferrocyanide of potassium in doing the latter. M. Rust considers the functions of the ferrocyanide to be also to restore to the steel nitrogen, upon which he looks as an important constituent of the metal. In 1850 a workman of Mulhouse, Alsace, sold the following receipt for a welding compound: 64 parts of borax, 20 parts of sal-ammoniac, 10 parts of ferrocyanide of potassium, and 5 parts of colophonium. M. Rust changed it as follows: 61 parts of borax, 17¼ parts of sal-ammoniac, 16¼ parts of ferrocyanide, and 5 parts of colophonium. He states that with the acid of this compound, welding may be accomplished at a yellow red, or at a temperature between the yellow red and white, and that no treatment is necessary after welding. The borax and sal-ammoniac are powdered, mixed and are slowly heated until they melt. Heating is continued until the strong odor of ammonia ceases almost entirely, a small quantity of water being added to make up for that lost by evaporation. The powdered ferrocyanide is then added, together with the colophonium, and the heating is continued until a slight smell of cyanogen is noticed. The mixture is allowed to cool by spreading it out in a thin layer. During the process given, boric acid and chloride of sodium are formed, ammonia being expelled. The same product may, therefore, be obtained by mixing 41.5 parts of boric acid, 35 parts dry chloride of sodium or salt, 15.5 to 26.7 parts of ferrocyanide of potassium, 7.6 parts of colophonium, and 3 to 5 parts of dry carbonate of soda. The only trouble with this mixture, which gives the same results, is that it decomposes easily unless it is kept in a dry place.

ENGINEERING STRUCTURES.

THE ST. GOTHARD RAILWAY.—The eighty-fourth monthly official report on the St. Gothard Tunnel works affords some interesting information as to the condition of this undertaking at the end of September last. From it we learn that as regards the main tunnel the enlargement to the full size of the arch had been carried out, through the whole distance, with the exception of a length of 131 ft. while the entire excavation had been completed for a length of 30,260 ft. The masonry of the lining of the arch was also completed for a length of 42,880 ft., and that the eastern and western sides for lengths of 32,440 ft. and 30,931 ft. respectively. Moreover, the portion of the tunnel completely finished, with waterways, refuges, etc., reached 30,504 ft., or about two-thirds of the whole length. The heading for the curved entrance tunnel at the Airolo end has also been made for a length of 233 ft., only 46 ft. remaining to be pierced. During the month of September the number of men employed on the main tunnel averaged 3051, while the total value of the works executed up to the end of the month reached 49,835,545 francs, or nearly two millions sterling. The average temperature of the air in the central part of the tunnel averaged during the month 84.2 deg. Fahr., while the maximum temperature was 89 deg. The daily consumption of oil in the tunnel averaged 1274 lbs., and of dynamite 518 lbs. As regards the railways which are being made in connection with the main tunnel, there has been executed up to the end of Sep-

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tember on the line between Immensee and Fluelen 62 per cent. of the earthworks and 59 per cent. of the masonry structures; on the length between Fluelen and Goschenen, 75 and 67 per cent.; between Airolo and Biasca, 77 and 88 per cent.; between Cadenazzo and Pirro, 67 and 73 per cent.; and between Giubiasco and Lugano, 63 and 39 per cent. of the two classes of works respectively. Altogether in the five lengths of line named there had been finished an average of 72 per cent. of the earthworks and 67 per cent. of the masonry. Of the 49 tunnels on the lines of approach to the main tunnel the direction headings have been driven from end to end in the case of 34, there being included in this latter number all the tunnels on the Immensee-Fluelen section, while in the Airolo-Biasca section the headings are pierced in eight tunnels out of thirteen. The value of the works executed on the approach lines up to the end of September was, according to the prices paid to the contractors, 29,537,300 francs, or about £1,181,490. During the month of September the average number of workmen employed on these approach lines was 13,420, of which number 6,040 were engaged in the tunnels.

SIPHON OVER THE SAINT MARTIN CANAL.—In order to carry out the new drainage works of the Bercy district, it was necessary to connect the sewers, which used to discharge into the Seine, with the main sewer on the opposite side of the St. Martin canal. This was accomplished by constructing an arched siphon over the canal, which, besides possessing the interest of novelty, was not liable, like a reversed siphon going under the canal, to collect deposit in its central portion. The rise of the siphon is 26 feet 3 inches, which renders the entire exhaustion of the air more difficult to maintain, as the pressure inside the siphon, being only about one-fifth of an atmosphere, some of the gas contained in the water is set free. Tromps were adopted for removing the air and gas. Two tromps with an inlet orifice of 1 inch diameter, and an outlet of 4 inches, sufficed to make a vacuum in six minutes which one tromp was then able to maintain. In order to reduce, as far as possible, the consumption of water in working the tromps, the flow through the supply pipe is controlled by a float. The float closes a valve whenever the vacuum is complete, and opens it again as soon as a further exhaustion is needed. By thus regulating the supply, or by using a third tromp with an inlet orifice of only $\frac{1}{8}$ inch, and an outlet of 4 inches, the consumption of water was only from 10,600 to 12,300 cubic feet in twenty-four hours. The siphon has been surmounted by a chimney, raised to a height of 34½ feet above the level of the sewers, at the top of which the tromps work. As the waters of the sewer cannot possibly be drawn up to this height, the tromps are by this means removed from all danger of obstruction. One important advantage of the method adopted is, that whereas lifting pumps might be unable to discharge the waters delivered after a great rainfall, the tromps are relieved from the necessity of working as soon as the siphon discharges more than from about 40 to 50 cubic feet per second, for then the current has sufficient velocity to carry off along with it all the gases which it sets free.—*Translated papers of the institution of Civil Engineers.*

SANITARY CONDITION OF THE ST. GOTHARD TUNNEL.—Such alarming accounts have been made public of the sufferings of the men employed in this work, that, at the instance of the Italian Government, the Swiss Federal Council appointed a committee of medical men to inquire into the matter. They have reported that there is no epidemic disease as was supposed, but that the unhealthy conditions under which the labor is carried on, induce chest complaints and other internal diseases, lower the general health, and above all produce anæmia, or deficiency of red particles in the blood. The temperature rises as they penetrate into the tunnel from 12 deg. Cent. to 31 deg. Cent.; the air is loaded with aqueous vapor, carries a large proportion of carbonic acid, and is rendered additionally impure by miasma from stagnant water, smoke of lamps, and human exhalations; there is little light, the ventilation is deficient, and the men are often working in water. In winter matters become still worse, as the frost prevents the effectual working of the air pumps. From the commencement of the work up to March of this year, the deaths among the employes have been 122, of which 47 were by accidents; and in the first three months of 1880, 90 men were dismissed with anæmia. The habit so general among Continental workmen of working all seven days of the week must be counted as one of the sanitary disadvantages; for those who took days of rest were found to resist best the unhealthy influences. The company provides medical and hospital accommodation, and seems to do what is in its power for the health of its men, and the help of the families of those who succumb.

A NEW RAILWAY BRIDGE ACROSS THE TEES. For some time past the directors of the North Eastern Railway have felt that the existing railway bridge which crosses the river Tees at Stockton is not sufficient for the increasing traffic of the district. They have, therefore, recently decided to construct a new bridge, and the Tees Side Iron and Engine Works Co. [limited], Middlesbrough—formerly Messrs. Hopkins, Gilkes & Co., who built the Tay Bridge—have been entrusted with the work. The erection of this bridge will form only a part of several proposed alterations, which will also include the diversion of the existing lines of rails, and the erection of a new iron station, which will be approached from Maudale road and Stockton Bridge road. The site of the new bridge will be a little to the east of the present one, and the structure will be so erected that it will carry the diversion of the Thornton road over the railway at a point where it intersects Darlington and Cleveland streets, thus giving improved facilities to the road traffic in these two important thoroughfares. The plans for the station have not yet been matured, but they will

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embody all the facilities that the public can reasonably require. The new bridge will immediately abut upon the existing one, and like it, will consist of three large water spans and one smaller land span on each side of the river; each of the large spans will be about 89 ft. 3 in. long, while the smaller ones will measure 28 ft. The level of the bridge will be 35 ft 6 in. above low water mark, and 23 ft. 6 in. above high water spring tides. The superstructure will consist of wrought iron plate web girders with wrought iron cross bars, and the rail-bearing girders are of the usual North Eastern type. The main girders measure 27 ft. 9 in. centers, 7 ft. 6 in. deep and 2 ft. 6 in. wide, while the cross girders—thirty of which are required for the bridge—are 8 ft. centers, 1 ft. 9 in. deep and 1 ft. 6 in. wide. The girders will be carried on four piers, each pier being composed of two cast-iron cylinders carrying a plate brick filling which is surmounted by a massive stone capstone. These cylinders will be sunk to a depth of 30 ft. below the bed of the river. The lower portions of the cylinders will be 10 ft. 6 in. in diameter, but about half way up it is reduced to 8 ft., and finishes with a regular tapering to 7 ft. at the top, upon which is placed a simple moulded cap. The metal will vary from 1⅜ in. at the bottom of the cylinder to 1¼ in. at the top. The whole structure is characterized by a neatness and simplicity of design which makes it admirably suited for the position in which it is placed, and the traffic it is designed to carry. The scantlings in all cases are, as in all North Eastern work, amply sufficient to carry the heaviest loads that can possibly be brought upon the bridge.—*Engineer.*

THE following particulars, descriptive of the Craigentinny system of sewage disposal, were recently given in a letter by an Edinburgh firm of civilian engineers: 1. The acreage of irrigated ground at Craigentinny is 250. 2. The population draining into the stream is fully 100,000. 3. The average quantity of sewage applied per acre was till last year about 11,000 gallons daily, but the Edinburgh water supply has been increased, and probably 15,000 gallons would be more correct now. 4. The sewage is only applied to the land about once every three weeks in rotation, and it is also used during the greater portion of each winter as well as in summer. 5. The sewage is applied for several hours each time—depending on the nature of the soil—four to eight hours or so at a time. 6. The cost is infinitesimal compared with the production, two or three men doing the whole work of flooding the land. 7. The produce consists entirely of grass, which is sold in plots by public roup each spring to the cowfeeders or dairymen, and is cut and carted away by them. 8. The average produce is 30 to 40 tons per acre, and the price per acre varies from about £25 to £45. 9. A great portion of the now irrigated meadows formerly consisted of stretches of land worth perhaps 10s. per acre. 10. It is an error to assume, as many seem to have done in England, that only sandy stretches are suitable for irrigation; as a rule, the better the soil the better the result obtained. 11. The notion of the irrigated meadows creating any nuisance of consequence, or being a source of any specific disease, has long been abandoned as untenable by our most distinguished medical men who have considered the subject, and by Dr. Littlejohn, medical officer of health for Edinburgh. Irrigation, like everything else, is a subject that requires careful consideration in each case, combined with some practical knowledge and experience, and it is probably the want of such caution that has caused so many disappointments and failures in dealing with the question.—*Engineer.*

RAILWAY NOTES.

WRITING on railway accidents in Germany, the Berlin correspondent of the *Daily News* draws attention to the condition of the German railways under State management. He says: "Another serious railway accident has occurred on the Belgian-German Frontier, near Herbesthal, on the direct Cologne and London line. A collision took place between a passenger train and a goods train with great violence. Eight persons were killed on the spot, and a large number severely injured. The frequency of serious accidents in Belgium, and especially in Germany, is at last beginning to attract attention here; and the English traveling public should not forget that the lines they mostly use are at present the most dangerous. On returning from Cologne last week, I was lucky enough to miss my train to Berlin, which I heard on the following day had been smashed up near Dortmund, with a large number of killed and wounded, Now that the Prussian railways have become state property, the government adopts the principle of economy in every branch of the railway service. For instance, the number of the line inspectors has been reduced to a minimum, one chief inspector being made responsible for so many hundred miles of line, over which it is practically impossible to give the necessary supervision under only one head. Secondly, when a railway accident does occur, such secrecy is observed that a long time elapses before the public are made aware of the exact number of dead or injured, and the matter is hushed up as soon as possible; and the press having no means of obtaining a true account, pays exceedingly little attention to these terrible disasters—that is to say, unless they happen in England, and then as much is made of them as possible. For the past fortnight not one single day has elapsed but an accident more or less serious has been curtly reported in the German papers as happening on German railways. I hear that the Progressists are going to interpellate the Prussian Parliament concerning the new state management of the railways. One thing certainly is striking, that under the new *regime* pointsmen only get 1s. 6d. to 1. 9d. per day."

FUNICULAR RAILWAY.—*La Nature* gives an interesting account of the funicular railway lately brought into use at the Giessbach, for conveying passengers between the pier and

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the hotel on the mountain side. This line is worked on the same principle as the convenient trams at Scarborough, by which people are carried up and down the cliff, i. e., two carriages are connected by a rope, so that one ascends while the other descends; the excess of weight being supplied to the descending carriage in the form of water. At the Giessbach, the line is a single one, except in a small portion at the middle, where the two carriages pass each other. This crossing is effected automatically. Six wheels of one carriage having all their flanges exterior, whilst those of the other have theirs interior, the rails being adapted in accordance, to give the desired result. A wagon for luggage is worked without the cable, by means of a toothed wheel catching in a rack-rail; this is driven by four men. The carriages have a pinion on the front axle, catching in the rack-rail; also brakes, and a catch which is raised by a counter weight while the cable is tense, but acts in case of rupture. The water is from a reservoir, supplied by the Giessbach fall. This railway is 346 meters long, and the slope in some parts is as much as 28ctm. per meter. A rising carriage filled with (40) passengers may weigh 9,500kg.; and the excess of weight for the other carriage is 1,300kg. The velocity is about 1 meter per second, so it takes 346 seconds (about 6 minutes) to make the journey.

A LARGE meeting at Victoria (Vancouver's Island) has passed a resolution declaring that separation from the Dominion would be the best course if the government of the latter fails to carry out its obligations with regard to the Pacific Railway.

A TRIAL was made in Berlin, in November, in the presence of Count Moltke, of a new traction engine, adapted to military purposes. This engine drew five heavy guns of 15 centimeter bore, through the streets for over two hours, at the cost of two marks an hour. The trial was considered by Count Moltke and the staff very satisfactory. Probably, the *Daily News* Berlin correspondent says, the traction engine will become an institution in the German army.

ACCORDING to intelligence from Paris in the *Presse*, which is confirmed from other quarters, the project of direct railway communication with Constantinople, *via* Roumania and Bulgaria, has been taken up very seriously. The report of M. de Serres, the engineer-in-chief of the Austrian Staatsbahn, who was sent last summer at the instance of the late M. Isaac Pereire, the president of the Paris Committee of the Austrian Staatsbahn, to open negotiations with the Roumanian and Bulgarian governments, convinced those who had taken up the idea, and also the late M. Isaac Pereire, of the feasibility of the scheme. It seems that a separate company, mostly composed of French capitalists, is to take in hand the scheme, and that the necessary capital needed has already been secured by subscription—nay more, for whereas the estimates show a necessity for a capital of only 60,000,000f., the company is to be formed with a capital of 100,000,000f. This has given rise to the supposition that there is a design of eventually extending the network in Bulgaria. The negotiations with the Roumanian and Bulgarian governments are said to be already so far advanced, that in both legislatures the law authorizing the company to build, and insuring it a handsome guarantee per mileage, is to be brought in shortly, so that the work may begin next spring. The anticipation may, perhaps, not be realized, but there seems little doubt that the scheme of this railway connection is now seriously entertained.

SPEAKING of a train which was blown over a precipice on the Wellington and Graytown Railway, New Zealand, on the 12th September last, the following particulars are given in the Melbourne *Argus*, and are more definite than any previous account which has reached us: The train was composed of—first, two composite carriages, then the ordinary guard's brake-van, then the Fell engine, then two luggage vans filled with furniture, produce and sundry goods, and, last, the incline brake van, with a guard in it. The wind on the plain was not stronger than usual, there being only an ordinary breeze; but as the train went up the mountain's side very strong gusts were felt at different spots, where the configuration of the hills allowed them to strike the train. Nothing, however, happened, and the train went on all right through the first tunnel, and had emerged through a cutting within fifty or sixty yards of the second or middle tunnel. This spot is called Siberia, on account of the violent and piercing blasts that sweep down the hollow of the hill. The line runs along a sort of embankment, formed from the stuff taken out in making the tunnel; but on the right side the hollow formed by the embankment side and the adjacent hill is only a few feet deep, while on the other side there is a steep declivity of over 100 feet, running down to a creek. The train was going slowly along this embankment, when the wind, catching it broadside with enormous force, without an instant's warning, lifted the two front carriages and van clean off the rails, and swung them around and down the deep embankment, one hanging to the other. The carriages were swung round farther than what would have been at right-angles with the rails, and as they were then motionless, formed an acute angle with the engine. The first carriage as it swung over went on its side, and the shock started the body from the bed and wheels. The body rolled away down, breaking to pieces as it went, and the wind carried the pieces in every direction. The second carriage was turned square on its side, and so remained, all the windows, of course, being shattered in. The van was partly thrown over, and rested obliquely, two wheels being sunk in the embankment, and the other two in the air. The engine, the two goods vans, and the other brake retained their position on the rails.

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ORDNANCE AND NAVAL.

THE INCREASING POWER OF GUNS.—A remarkable result has recently been achieved by Sir W. Armstrong and Co. in the production of a gun, weighing 95 cwt., discharging a projectile weighing 120 lbs., with a velocity of 2064ft. per second—that is to say, having 3545 foot-tons stored-up energy, or 746.3 foot-tons per ton weight of guns. The gun is an experimental one, and we should suppose that such a result must be exceptional, being, of course, very extraordinary, and a stride in advance even of the 613.5 foot-tons per ton of gun obtained by the 6in. Armstrong, reported in *The Engineer* of November 5th. At present we speak of this as an abnormal individual result. How much the gun is able to bear as a regular service round we cannot say. The fact, of course, indicates something unprecedented. In recording this we would take the opportunity of correcting an expression which may mislead a reader in the article of November 5th above referred to. We there spoke of a delicate point, namely, the question of priority of Armstrong 6in. and Krupp's 15-centimeter guns, whose results we compared together. Speaking from the reports of each lying before us, we considered that the two pieces dated from about the same time. In doing so we unconsciously did injustice to the Armstrong gun; for while Krupp's pamphlets, issued at the Meppen trials, as we understand them, contain the records obtained of their earliest private trials, which took place on December 17th, 1878, the report of the Armstrong results dealt only with a certain series of Government trials. Previous to this, we have now ascertained, a Government trial had taken place on May 2nd, 1878, and private trials as early as December, 1877. This, it will be seen, argues a year precedence for Armstrong as compared with Krupp, which in a question of this kind may mean everything, and should certainly be clearly stated.

ROBERTS'S RANGE FINDER AT WOOLWICH. Captain Roberts, R.A., recently described a range finder designed by himself to an Artillery audience, General Turner, C.B., the commandant of the garrison, and his staff being present. This range finder mainly consists of a telescope with large field, such as it is proposed to issue to field batteries, mounted on a tripod stand, with cross lines and prism. The glass is directed at the object, and the prism then applied so as to cause the line of vision to be deflected at a right angle to a staff carried on the shoulder of an assistant, and correctly placed by means of a second small glass and optical square. Numbers are read off, for the use of which the range can be read off a slide rule. The operation is a rapid one for intelligent men. It would not here be fair to compare it with Watkins' or Nolan's systems. It is, at all events, a matter for congratulation that so much interest should be displayed in range finding by combatant officers. The best conceivable range finder might be introduced to the committtee, without after all achieving much, unless an efficient system of instruction is set on foot by the Adjutant-General.

BOOK NOTICES.

PUBLICATIONS RECEIVED.

MONTHLY Report of the Meteorological Bureau for October.

Papers of the Engineer Department, U. S. Army, contains: Hollow Brick Foundations, Arches in Masonry Bridges. By Wm. H. Bixby, Lieutenant of Engineers, Washington: Government Printing Office.

Les Tarifs des Chemins de Fer, par N. C. Leon Augoc. Paris; Dunod.

MODERN ARCHITECTURAL DESIGNS AND DETAILS.—Nos. II. and III. New York: Bicknell & Comstock. Price, $1.00 each.

This excellent work maintains the excellent character exhibited in the first issue. The style of the designs and the finish in execution make this work invaluble to the young architect.

Suburban cottages in wood form the illustrated subjects of the two numbers before us. The minuteness of detail leaves nothing to be desired in the way of completeness.

THE CURRENT GOLD AND SILVER COINS OF ALL NATIONS. By IVAN C. MICHELS. Ph. D., M. A. Philadelpha: R. S. Menarnin. For sale by D. Van Nostrand. Price, $3.00.

This is an illustrated quarto, giving by pictorial illustration and tables all that can be desired in the way of information about gold and and silver coins.

Weights, fineness and intrinsic values are reduced to United States standard.

The entire history of United States coinage is given from 1792 to the present time.

To facilitate the use of this work a complete alphabetical index is added.

A PHYSICAL TREATISE ON ELECTRICITY AND MAGNETISM. By J. E. H. GORDON, B. A. New York: 1880. Price, $7.00.

In the present time of rapid progress in practical electrical science, every new treatise is scanned in expectation that it contains something new in the way of exposition of the later recognised phenomena. The great need has, however, been of late a treatise that should discuss collectively the phenomena of electricity and magnetism from the physical standpoint only, as distinguished from the mathematical, and should, moreover, regard the work of the practical electricians as something within the province of accepted theories.

The present work seems to accomplish this. Under the head of Electro Statics, all the ordinary experiments of the lecture room in frictional electricity are discussed, together with all the elaborate devices of the philosophers used in their researches. Under magnetism all that relates to magnets, terrestrial magnetism and the delicate methods of measuring and recording the latter.

Electro kinetics covers a wider field; and be-

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ginning with battery cells the author passes to the consideration of the units of measure and their application in practical uses. Electro magnetism and magneto electricity are discussed under this heading; also the various phenomena produced by the induction coil, secondary batteries and the laws of electrolysis.

Electro-optics forms part four and closes the work.

Throughout the treatise the works of the leading philosophers are described and their opinions quoted. All varieties of instruments of research are fully illustrated and their objects and uses described.

This work is undoubtedly the most complete compendium of electrical science in the English language.

PRACTICAL BLOWPIPE ASSAYING. By GEO. ATTWOOD, A. I. C. E. New York; D. Van Nostrand. Price, $2.00.

Quantitative assaying with the mouth blowpipe is a difficult process. Plattner's voluminous treatise has been followed by the few who have acquired enough proficiency to feel confidence in their results, but even with the most enthusiastic students, the success under this guidance is so out of proportion to that attained with similar effort in *qualitative* determinations that but few have patience to acquire any considerable skill in determiningthe quantities in their essay.

The present treatise, recognizing fully the difficulties of the process, proceeds in the most concise way to inspire confidence in the learner and lead him to adopt sure and available methods to insure success.

First, the elementary bodies are mentioned and directions given for their determination separately. This, with the description of the apparatus and reagents constitute the first two parts of the work.

Part III is devoted to the assaying of silver, gold, mercury, copper, lead, bismuth, tin, iron, nickle, cobalt and coal.

The author suggests a useful check in the way of synthetic assays, which consists in the preparation of weighed quantities of the pure element or elements to be determined, mixed with materials resembling as nearly as possible the ore to be determined. Any loss of the element sought in the artificial mixture serves as a guide to correct the regular assay.

Part IV. contains useful tables. The illustrations and typography are excellent.

The book is designedly of convenient size for carrying while prospecting.

A TREATISE ON METEOROLOGICAL INSTRUMENTS. By Negretti & Zambra: London. For sale by D. Van Nostrand. Price, $2.00.

The fame so justly earned by these makers of scientific apparatus gives weight to their statements regarding the instruments employed in any department of scientific labor.

For the proper care and use of meteorological instruments, an instruction book is indispensable, such a treatise is provided with this minute description of the construction of the instruments.

Five chapters are devoted to barometers alone, five chapters to thermometers; then follow chapters on hygrometers, rain-gauges, anemometers, electroscopes and ozonometers.

Tables for barometers and boiling-point thermometers are added.

The text is embellished with ninety-eight wood cuts.

NEGRETTI & ZAMBRA'S DESCRIPTIVE CATALOGUE OF PHILOSOPHICAL INSTRUMENTS. Negretti & Zambra: London. For sale by D. Van Nostrand. Price, $2.50.

The peculiarity of this catalogue is that the construction of the apparatus is so far described, and the range of subjects so comprehensive, that the so-called catalogue becomes an exceedingly convenient encyclopedia.

An occasional essay on the progress in some department of scientific research increases the usefulness of this handy volume.

There are several hundred illustrations distributed through 540 pages of royal octavo text.

MISCELLANEOUS.

LEHMANN'S HOT-AIR ENGINE.—The risks and trouble incidental to the application of steam to engines of small power are now generally recognized. A steam boiler must always have close and personal attention by a fairly skilled or practiced hand. These needs for attention and possible dangers, are avoided by the use of heated air as a source of power instead of steam. The elasticity and expansion of air heated to 600° or 800° Fahrenheit is sufficient to develop an appreciable pressure, and thus to enable a small engine to be driven up to a moderate power, such as that of a half or one horse. Larger powers may of course be obtained, but will require larger diameters of cylinders, as the effective pressure to be obtained by the expansion of the hot air is not capable of any great increase. The engine we illustrate herewith is Lehmann's patent, manufactured by Messrs. W. H. Bailey & Co., of Salford, Manchester, and is a very well designed and effective specimen of its class. The construction of the engine is horizontal, the heating apparatus consisting of a brick-built furnace. In this is fitted a steel air heater which may be raised to a dull red heat. The working cylinder is fixed outside the furnace, and its front part is jacketed by water jacketing. A cold chamber is thus provided in which the expanded air is condensed and contracted to its original volume. The working piston is an open plunger, which is made air tight by a cup-leather packing. As this packing is fixed in the cold portion of the engine it does not suffer from the heat, and will last a long time without attention, whilst at the same time it forms a tight and frictionless method of packing. It has always been difficult to apply a piston packing in these engines which will stand the heat of the air. Any class of packing, which must be packed by a gland, would also offer on a large plunger far too great a proportion of frictional resistance in engines of such small power as those worked by hot

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air. The working plunger operates directly upon a rocking lever, to the end of which is attached the connecting rod driving a crank and fly-wheel carried in bearings on the top of the cylinder. A circulating pump to supply the water jacket is fixed on the bed-plate, and driven from a rocking bar by a return crank and connecting rod. The hot air is first expanded in the hot chamber which causes the piston to drive forward, the air then escapes at the end of the stroke, and by passing through a cold chamber is reduced to its former bulk, and may be thus returned to the hot chamber without much back pressure on the piston or plunger. The same volume of air is thus used continuously, first being expanded and then contracted for the working and back strokes respectively. No foul heated air is thus discharged by the engine, to which there is no exhaust.

It is somewhat surprising to note the immense rapidity with which the air can absorb heat and give it up again, as we find that as many as 1000 revolutions per minute have been obtained from the smaller sizes. This power of speed will no doubt depend upon the skillful arrangement and extent of surface of the heating and cooling chambers. This engine appears to be very economical, as the makers state that a 1-horse engine will run for twelve hours at a consumption of 50 lbs. of coke. A great advantage also is that such an engine may be safely left to run itself down, since no damage can ensue to it, as it will only stop when the fire gets to low. In this way Lehmann's engine may be left to run all night without any attendance or the fear of a mishap. When applied to farm or domestic purposes the engine need cost little or nothing to work, as the heat of the stove may be utilized for warming purposes, and even the hot water from the cooling jacket would be found serviceable. A pumping apparatus may be attached to the bed plate of the engine so as to form a compact and serviceable pumping engine.

SOMETIME ago the executive committee of the Citizens' Association of Chicago appointed a sub-committee to consider the subject of house drainage. That committee consisted of Frederick Baumann, James R. Willett and Bryan Lathrop. After considerable investigation and prolonged deliberation the committee has embodied its ideas in a report, of which the following is a brief summary of the recommendations made:

1. Concrete the ground under the entire building.

2. Ventilate the main sewers by a perforated cover on every man-hole.

3. Every house to have a cast iron soil pipe, not less than four inches in diameter and one-quarter inch in thickness, tarred inside and outside, running from sewer to roof, without a trap, accessible for inspection throughout its entire length, and with as great a fall as possible; the openings for waste and soil pipes in the house walls to be larger than the pipes, to allow for settling.

4. Every sink, wash basin, bath tub and water closet (except the "trapless" closets) to be trapped.

5. Every trap to be ventilated from its highest point into a pipe running out above the roof, and disconnected from the soil pipe.

6. Joints in iron pipes to be leaded and caulked to rust joints. Joints between iron and lead pipes to be made with tinned iron or brass ferules, soldered.

7. Catch-basins to be built outside of the house wherever possible, and ventilated by a special pipe.

8, Water closets to connect with the outer air by a window or light shaft, and to have a ventilating flue.

9. Avoid pan-closets, and use hopper or improved closets.

10. On the upper floor each water closet to be flushed from a separate tank through a pipe not less than one and one quarter inch in diameter.

11. Catch-basins to be periodically cleaned by the city authorities.

Sanitary Legislation.—It is the custom of all cities to control, by municipal ordinance and by supervision, matters affecting the public health. Nothing can more properly come within the scope of municipal legislation than measures regulating house drainage, in order to prevent, as far as possible, the generation and spread of infectious diseases. It is obviously necessary to make the precautions obligatory upon all the people, as their efficacy depends on the general use of them, and it is to the interest of all that they should be universally adopted. Your committee, therefore, recommend that an ordinance be passed by the common council of Chicago embodying the most important of the foregoing recommendations, as follows:

1. That every house which shall be connected with the city sewers, after this ordinance goes into effect, shall have a continuous pipe of not less than four inches inside diameter, running from the street sewer to at least two feet above the roof of the house, without any trap throughout its entire length; the opening at the house wall to be larger than the soil pipe, to allow for settling.

[NOTE.—As there may be some who will prefer to use a trap on the house drain or soil pipe, this vent pipe may in that case be made independent of the house drainage, and be carried through the house without any opening into it.]

2. Every sink, basin, bath tub and water closet (except "trapless" closets) to be trapped, and every trap to have a vent pipe from its highest point.

3. Joints in iron pipes to be leaded and caulked or rust joints. Joints between iron and lead pipe to be made with tinned iron or brass ferules, soldered.

4. Soil pipes to be of iron.

5. All water closets to be connected with the outer air by a window and ventilating flue or a light shaft.

6. Sanitary inspectors to be appointed, under the direction of the health commissioners, to enforce the observance of the foregoing provisions.

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THE EARTH'S MAGNETISM.—The great physical problem of terrestrial magnetism has engaged the attention of numerous physicists lately, and it is well known that several ingenious solutions of it have been propounded. Professors Ayrton and Perry, for example, conceived the happy thought that the earth was charged with static electricity, which being carried round on the surface by the diurnal rotation, acted like a circulating current and magnetized the core. A severe blow was dealt to this hypothesis, however, by the mathematical criticism of Professor Rowland, who pointed out that the surface charge required was competent to send a spark from earth to moon. A theory based upon the existence of electric currents flowing in the atmosphere around the earth was promulgated later; and now we have another supposition, which has a better claim to serious attention than any of the rest because it is supported by direct experiment. Starting from the idea of M. Edlund that an electric current is really an ether current flowing in the circuit, and that electrostatic effects are due to rarefactions and condensations of the ether, M. Selim Lemström considered that he might produce this ether current by mechanical action. He, therefore, made a paper tube having two concentric walls and mounted on an axle. A core of soft iron was placed within the tube, and on rotating the latter the core was found to be magnetic, as demonstrated by two fine astatic needles. Reversing the rotation, reversed the magnetic poles; and M. Lemström concludes that the relative motion of the ether in the revolving tube and the stationary core was the cause of the polarity. It follows that if the tube be stationary and the core revolved a similar effect will be produced; and hence if a magnetic body like the earth be rapidly rotated round its axis in an insulating medium like the air, it will exhibit magnatism. Pursuing this idea into mathematics M. Lemström arrives at an expression for the magnetic moment of the which agrees very well with the formula of Gauss.

AN ELECTRO-DYNAMIC PARADOX.—Dynamo-electric machines like M. Gramme's are reversible, and can either generate a current from mechanical work or from a current produce mechanical work. Under the same conditions continuous current magneto-electric machines do the same thing. But if the current from a dynamo-electric machine is sent into a magneto-electric machine a very strange effect results. This effect is signalled by M. Gérard-Lescuyer, who calls it an electro-dynamic paradox. Soon as the circuit is closed the magneto-electric machine begins to move, and tends to acquire a speed proportional to the intensity of the current actuating it. But suddenly it slackens speed, stops, and then begins to rotate in the contrary direction, only to arrest itself anew and begin again as before. In a word, it exhibits a regular alternative motion, lasting as long as the current which actuates it. What, asks M. Lescuyer, is the cause of this phenomenon? Evidently the motive current changes its direction; and a galvanometer introduced into the circuit proves it. But how does it produce itself when the speed of the prime mover, be it steam or other engine, does not vary? The effect must be due to an exterior cause reversing the polarity of the inductors of the dynamo-electric generator so as to cause it to give birth to a reversed current. This reversal is proved by placing a compass near the inductors, and this reversal keeps time with the reversal of the current, as shown by the galvanometer in circuit with the machines. Let us suppose that the magneto-electric receiver has periodic increases of velocity. These will give rise to a current of its own in the magneto-electric machine, which will traverse the dynamo-electric machine, and as it will be a contrary current to that coming from the latter it will tend to reverse the polarity of the inductors of the dynamo machine. Hence a reverse current will proceed from the latter. To test this hypothesis it is sufficient to prevent the increase of the velocity in the magneto-electric receiver by means of a brake. As soon as the brake is put in play the paradoxical effect vanishes, and the receiver goes uniformly in the same direction, whilst the galvanometer and compass are unaffected. The experiment is well shown by a Siemens dynamo-electric continuous current machine for generator, and a small laboratory Gramme with ordinary permanent magnets, as constructed by M. Breguet, for receiver.—*The Electrician.*

ASTRONOMY IN ROCHESTER.—The new Warner Observatory which is being erected at Rochester, N. Y., is attracting much attention in social and literary as well as scientific circles. The new telescope will be twenty-two feet in length, and its lens sixteen inches in diameter, thus making it third in size of any instrument heretofore manufactured, while the dome of the Observatory is to have some new appliances for specially observing certain portions of the heavens. It is to be the finest private observatory in the world, and has been heavily endowed by Mr. H. H. Warner. Professor Swift has labored under numerous disadvantages in the past, and the new comet which he recently found was in spite of many obstacles; but as the new institution is to be specially devoted to discoveries there are good reasons to expect very many scientific revelations in the near future from the Warner Observatory at Rochester.

A MAN on board the Livadia was asked on Saturday evening last to support an electric lamp temporarily, while arrangements were being completed for hoisting it to its position, and by mistake placed his hand in such a position as to divert the current from the candle through his body. He was killed instantaneously.

THE coal beds on the Souris River, Manitoba, a southern affluent of the Assiniboine, have, it is said, turned out rich, and will be developed during the coming winter. The Souris being only navigable in the spring time, it is proposed to float the coal down in flat-bottom scows.

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VAN NOSTRAND'S

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THE GEOMETRICAL INTERPRETATION OF IMAGINARY QUANTITIES.

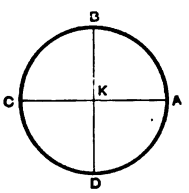
Translated from the French of M. Argand by Prof. A. S. HARDY.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

II.

IT is to be observed that while there exists an infinite variety of directed lines, practically they are all referred, as will be shortly shown, to $\overline{KA}$, $\overline{KC}$, $\overline{KB}$, $\overline{KD}$, the position unit being $\overline{KA}$ the negative $\overline{KC}$ and the means $\overline{KB}$ and $\overline{KD}$ (Fig. 4).

Fig. 4.



It is, furthermore, convenient to classify any two opposite directions under one head, to which we shall apply the term *order*. The primitive $\overline{KA}$ with its negative $\overline{KC}$ we shall designate as the *prime order*, and the means $\overline{KB}$ and $\overline{KD}$ as the *medial order*. We shall speak of a *prime quantity* or *medial quantity* when we refer to one of a *prime* or *medial order*, respectively. These terms are derived from the mode of generation of these quantities, and from the conception under which they are regarded real. We might apply the general term *intermedials* to all others which it is not necessary to designate specially.*

8. In accordance with what precedes, we may also modify the language of so-called *imaginaries* in such a way as to render this part of the subject more simple. In writing $+a\sqrt{-1}$ or $-a\sqrt{-1}$, we indicate explicitly the way in which the quantity is generated, which in certain cases may be useful; but ordinarily we leave the mode of generation out of consideration, and $\sqrt{-1}$ is only a particular kind of unit to which the number a is referred. It is, therefore, not absolutely essential to keep the mode of generation in view. Again, the expression $a\sqrt{-1}$ shows $\sqrt{-1}$ to be a multiplier of a; but really $\sqrt{-1}$, in $a\sqrt{-1}$, is no more a factor than is $+1$ in $+a$, or -1

*It has been already remarked that the relations said to exist between lines, when we take their directions into account, cannot as yet be regarded other than hypothetical. It is, therefore, very far from our purpose to propose the substitution of the nomenclature above described for that commonly employed; but to make use of it only because, in general, it is desirable to avoid the employment of terms whose real meaning is at variance with the ideas we wish to express, even when we are concerned with an hypothesis.

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in $-a$. Now we do not write $+1.a, -1.a$, but simply $+a, -a$, and the sign which precedes a itself indicates what kind of a unit this number expresses. We may then apply a similar method to imaginary quantities, writing for example $\sim a$ and χa instead of $+a\sqrt{-1}$ and $-a\sqrt{-1}$, the signs $\sim$ and χ being reciprocally positive and negative. To multiply these signs, we observe that either multiplied by itself gives $-$, and, consequently, multiplied by each other they give $+$. Moreover, a single rule, applicable to any number of factors, may be established; let every straight line, horizontal or vertical, in the signs to be multiplied, have a value 2, and every curved one a value 1; we shall have for the four signs the following values:

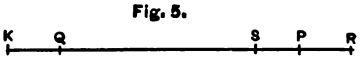
$$\sim=1, \quad -=2, \quad \chi=3, \quad +=4.$$

Then take the sum of the values of all the factors and subtract as many times 4 as is necessary to make the remainder one of the numbers 1, 2, 3, 4; this remainder will be the value of the sign of the product; and so, for division, subtract the sum of the sign values of the divisor from that of the dividend, having added if necessary a multiple of 4 to the latter, and the remainder will indicate the sign of the quotient. It is to be noticed that these operations are those of multiplication and division by logarithms; this analogy will be brought more fully into view.

These new signs would abridge the notation,* and perhaps render the calculus of imaginaries more convenient, errors of sign being sometimes easily made.† We shall employ them in what follows, without implying on that account that they should be adopted. Doubtless to every innovation, even a rational one, there is an intrinsic objection; but no progress would be made if they were rejected, for the only reason that they are contrary to usage, and their trial, at least, is permissible.

9. We are now to examine the various ways in which directed lines are combined by addition and multiplication, and to determine the resulting constructions. Suppose, first, that we have to add to the positive prime line $\overline{KP}$ (Fig. 5) the line $\overline{KQ}$, also a positive

Fig. 5.



prime; the construction would not differ from that of finding the sum of the absolute lines KP, KQ; it consists in laying off the distance $\overline{PR}=\overline{KQ}$ on the prolongation of $\overline{KP}$. We then have $\overline{KP}+\overline{KQ}=\overline{KP}+\overline{PR}=\overline{KR}$. To add a negative prime line $\overline{QK}$ to another $\overline{PK}$, the construction is the same, but in the opposite direction, and we should have $\overline{PK}+\overline{QK}=\overline{PK}+\overline{RP}=\overline{RK}$. In general, if we are to add two lines of the same direction, $\overline{AB}$, $\overline{AC}$, we take in this direction, $\overline{PQ}=\overline{AB}$, $\overline{QR}=\overline{AC}$, and we have $\overline{PQ}+\overline{QR}=\overline{AB}+\overline{AC}=\overline{PR}$. If we are to add to the positive line $\overline{KP}$ the negative $\overline{QK}$, we take a distance $\overline{PS}=\overline{QK}$ in the negative direction from P, and obtain $\overline{KP}+\overline{QK}=\overline{KS}=\overline{QP}$. The same course is pursued for any other order.

Now, the principle underlying these constructions is that we regard P, the final point of $\overline{KP}$, as the initial point of the line to be added, and that we take respectively for the initial and final points of the sum, the initial point of $\overline{KP}$ and the final point of the added line. Applying this same principle to lines of other orders, we conclude that K, P, R, being any points whatever, we always have $\overline{KP}+\overline{PR}=\overline{KR}$; and as each of the lines $\overline{KP}$, $\overline{PR}$ may also be the sum of two lines, as $\overline{KM}+\overline{MP}$, $\overline{PN}+\overline{NR}$, M and N being arbitrarily chosen, we conclude that, in general, A, B; M, N, O, ..., R, S, T being any points whatever, $\overline{AB}=\overline{AM}+\overline{MN}+\overline{NO}+\overline{O}\ldots+\ldots+\ldots\overline{R}+\overline{RS}+\overline{ST}+\overline{TB}$. The points A, B, M, ... may coincide or be so situated that the lines $\overline{AM}$, $\overline{MN}$, ...

*The quantity $m \pm n\sqrt{-1}$ being denoted by $m\sim n$, or by $m\chi n$, the single sign $\sim$, or χ, replacing the four signs $+, \sqrt{-}, -, 1$.

†For example, let it be required to multiply $-m\sqrt{-c}$ by $+n\sqrt{-cd}$. The product of the two coefficients is $-mn$; that of the two radicals is $-c\sqrt{d}$; and the final product is $+mnc\sqrt{d}$. In the new notation the two factors are $\sim m\sqrt{c}$, $\chi n\sqrt{cd}$, or $\chi m\sqrt{c}, \sim n\sqrt{cd}$, and by the rule we at once obtain $+mnc\sqrt{d}$. This advantage—if it be one—would not exist for an experienced calculator, who by a simple inspection of the factors would read the product; but not every one possesses this faculty.

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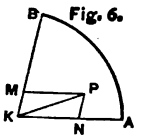
coincide, intersect, etc. These circumstances are matters of indifference.*

10. Every directed line may thus be decomposed in an infinite number of ways. To decompose, for example, the line $\overline{KP}$ (Fig. 6) into two, one of an order $\overline{KA}$, the other of an order $\overline{KB}$;

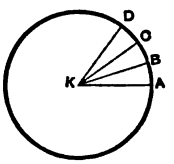
Fig. 6.



draw, through P, PN parallel to BK, and we have $\overline{KP}=\overline{KN}+\overline{NP}$. Or we might draw PM parallel to KA, and then $\overline{KP}=\overline{KM}+\overline{MP}$; but these two expressions are identical, because $\overline{KM}=\overline{NP}$ and $\overline{KN}=\overline{MP}$. As there is no other way to effect the proposed decomposition, we conclude that, if A and A′ are of the order a, B and B′ of another order b, and we have the equation $A+B=A'+B'$, then $A=A'$, $B=B'$.

11. Let us now pass to the multiplication of directed lines, and let us first construct the product $\overline{KB}\times\overline{KC}$ (Fig. 7),

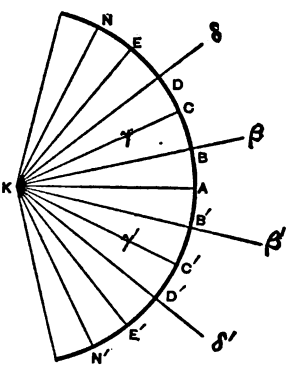
Fig. 7.



the factors being units, but not prime units. Construct the angle $\overline{CKD}=\overline{AKB}$. From what was said in No. 4, Note I, we have $\overline{KA}:\overline{KB}::\overline{KC}:\overline{KD}$, whence $\overline{KA}\times\overline{KD}=\overline{KB}\times\overline{KC}$; but $\overline{KA}=+1$, hence $\overline{KB}\times\overline{KC}=\overline{KD}$. Therefore, to construct the product of two directed radii, lay off, from the origin of arcs, the sum of the arcs corresponding to each radius, and the extremity of the arc thus laid off will determine the position of the radius of the product; this, as before, is logarithmic multiplication. It is unnecessary to show that this rule applies to any number of factors. If the factors are not units, they can be put under the form $m.\overline{KB}$, $n.\overline{KC}$, . . ., m and n being coefficients or positive prime lines, and the product would be $(mn\ldots.)\,.\,(\overline{KB}\,.\,\overline{KC}\ldots.)=(mn\ldots)\,.\,\overline{KP}$. Now, the product of the positive prime line $(mn\ldots)$ by the radius $\overline{KP}$ is this very line, drawn in the direction of this radius. Division is the inverse of this operation, and its explanation in detail is unnecessary.

12. By means of these rules we may operate on directed lines as on absolute ones. We now proceed to some applications of the principles already laid down, and we shall first state some immediate consequences which are of most frequent use.

Fig. 8.



§1. If AB, BC, ... , EN (Fig. 8) are equal arcs, n in number, and we make $\overline{KB}=u$, we shall have $\overline{KC}=u^2$, $\overline{KD}=u^3$, ... , $\overline{KN}=u^n$.

§2. If we lay off the arcs below KA, as AB′, B′C′, ... , E′N′, we shall have

$$\overline{KB'}=\frac{1}{u},\ \overline{KC'}=\frac{1}{u^2},\ \ldots,\ \overline{KN'}=\frac{1}{u^n}.$$

§3. Hence

$$\frac{\overline{KB}}{\overline{KB'}}=u^2,\ \frac{\overline{KC}}{\overline{KC'}}=u^4,\ \ldots,\ \frac{\overline{KN}}{\overline{KN'}}=u^{2n}.$$

§4. If, on corresponding radii, we take $K\beta=K\beta'$, $K\gamma=K\gamma'$, $K\delta=K\delta'$, ... , the distances $K\beta$, $K\gamma$, $K\delta$, . . . being arbitrary, we obtain

$$\frac{\overline{K\beta}}{\overline{K\beta'}}=u^2,\ \frac{\overline{K\gamma}}{\overline{K\gamma'}}=u^4,\ \frac{\overline{K\delta}}{\overline{K\delta'}}=u^6,\ \ldots\ .$$

*This rule is reached by induction, and what was said in the note to No. 4, on the geometrical ratio of directed lines, is here applicable.

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§5. If on the radii $\overline{KA}$, $\overline{KM}$, $\overline{KN}$ as bases, similar and equal figures be constructed, $\overline{a}$, $\overline{m}$ and $\overline{n}$ being homologous lines, then $\overline{m} = \overline{a} \times \overline{KM}$, $\overline{n} = \overline{a} \times \overline{KN}$, whence $\frac{\overline{m}}{\overline{KM}} = \frac{\overline{n}}{\overline{KN}}$, or $\overline{m} . \overline{KN} = \overline{n} . \overline{KM}$.

§6. MN being any arc of the circumference, it may at times be convenient to denote, in general, by $\overline{K.MN}$ the directed radius drawn though the extremity B of the arc AB=MN, A always being the origin of arcs. We should thus have

$$\overline{K.MN} \times \overline{K.PQ} = \overline{K.(MN+PQ)},$$

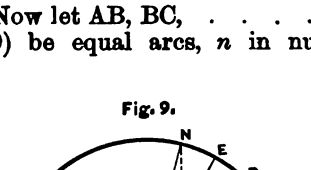
and $$\frac{\overline{K.MN}}{\overline{K.PQ}} = \overline{K(MN-PQ)}.$$

§7. If $\overline{KB}$ has the same direction as $\overline{PQ}$, we have $\overline{PQ} = PQ \times \overline{KB}$; for the absolute line PQ may be regarded as positive prime.

§8. If we have the equation $r' . \overline{PQ} = r'' . \overline{MN}$; r', r'' being unknown directed radii, and $\overline{PQ}$, $\overline{MN}$ lines of the same direction, or absolute lines, it follows that $r' = r''$, and consequently $\overline{PQ} = \overline{MN}$, or PQ=MN.

13. Now let AB, BC, ... , EN (Fig. 9) be equal arcs, n in number;

Fig. 9.



then $\overline{KN} = \overline{KB}^n$; but $\overline{KN} = \overline{K\nu} + \overline{\nu N}$, and $\overline{KB} = \overline{K\beta} + \overline{\beta B}$; hence

$$\overline{K\nu} + \overline{\nu N} = (\overline{K\beta} + \overline{\beta B})^n.$$

Let the arc AB=a, and, therefore, AN=na; then $\overline{K\beta} = \cos a$, $\overline{K\nu} = \cos na$, $\overline{\beta B} = \sim \sin a$, $\overline{\nu N} = \sim \sin na$; and the above equation becomes

$$\cos na \sim \sin na = (\cos a \sim \sin a)^n.$$

This theorem, expressed in the ordinary notation by

$$\cos na \pm \sqrt{-1} \sin na = (\cos a \pm \sqrt{-1} \sin a)^n,$$

is a fundamental one in the theory of circular functions; among its uses is the expansion of $\sin x$ and $\cos x$ into series.

Developing the binomial, equating separately the terms of the same order, and dividing by ~ 1 the equation between the medials, we have the expressions for $\cos na$ and $\sin na$; then making $na = x$, and supposing n to increase and a to diminish, x remaining constant, we have, at the limit,

$$\cos x = 1 - \frac{x^2}{2} + \frac{x^4}{2.3.4} - \frac{x^6}{2.3.4.5.6} + \ldots,$$

$$\sin x = x - \frac{x^3}{2.3} + \frac{x^5}{2.3.4.5} - \frac{x^7}{2.3.4.5.6.7} + \ldots.$$

14. From $\overline{KN} = \overline{KB}^n$ we have $\overline{KB} = \overline{KN}^{\frac{1}{n}}$, whence

$$\overline{K\beta} + \overline{\beta B} = (\overline{K\nu} + \overline{\nu N})^n = \overline{K\nu}^{\frac{1}{n}}$$

$$+ \frac{1}{n} \overline{K\nu}^{\frac{1}{n}-1} . \overline{\nu N} + \frac{\frac{1}{n}\left(\frac{1}{n}-1\right)}{2} \overline{K\nu}^{\frac{1}{n}-2} \overline{\nu N}^2$$

$$+ \frac{\frac{1}{n}\left(\frac{1}{n}-1\right)\left(\frac{1}{n}-2\right)}{2.3} \overline{K\nu}^{\frac{1}{n}-3} . \overline{\nu N}^3 + \ldots.$$

$$= \overline{K\nu}^{\frac{1}{n}} \left\{ 1 + \frac{1}{n} \frac{\overline{\nu N}}{\overline{K\nu}} + \frac{\frac{1}{n}\left(\frac{1}{n}-1\right)}{2} \cdot \left(\frac{\overline{\nu N}}{\overline{K\nu}}\right)^2 + \right.$$

$$\left. \frac{\frac{1}{n}\left(\frac{1}{n}-1\right)\left(\frac{1}{n}-2\right)}{2.3} \cdot \left(\frac{\overline{\nu N}}{\overline{K\nu}}\right)^3 + \ldots \right\}.$$

Substituting the preceding values of $\overline{K\nu}$ and $\overline{\nu N}$, and noticing that

$$\frac{\overline{\nu N}}{\overline{K\nu}} = \frac{\sim \sin na}{\cos na} = \sim \tan na,$$

equating separately the terms of the same order, multiplying the equation between the medials by $\frac{n}{\sim 1} = \chi n$, and making the same supposition as before, there results

$$x = \tan x - \frac{\tan^3 x}{3} + \frac{\tan^5 x}{5} - \frac{\tan^7 x}{7} + \ldots.$$

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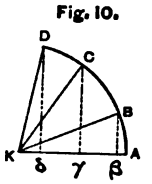
15. Let (Fig. 10) the arcs $AB=a$,

Fig. 10.



$AC=b$, and let CD be taken equal to AB. Then (No. 11), $\overline{KD}=\overline{KB}\times\overline{KC}$. But

$\overline{KD}=\overline{K\delta}+\overline{\delta D}=\cos(a+b)\sim\sin(a+b)$,
$\overline{KB}=\overline{K\beta}+\overline{\beta B}=\cos a\sim\sin a$,
$\overline{KC}=\overline{K\gamma}+\overline{\gamma C}=\cos b\sim\sin b$; hence

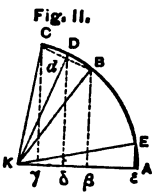
$$\cos(a+b)\sim\sin(a+b)=(\cos a\sim\sin a)(\cos b\sim\sin b).$$

Expanding the second member and equating the orders separately, we have

$$\cos(a+b)=\cos a\cos b-\sin a\sin b,$$
$$\sin(a+b)=\cos a\sin b+\sin a\cos b.$$

16. Let $AC=a$, $AB=b$ (Fig. 11); draw

Fig. 11.



the chord BC, and the radius KD, bisecting the angle BKC. Make $AE=BD=\frac{a-b}{2}$, and draw KE and Eε. Then

$\overline{K\gamma}+\overline{\gamma C}-(\overline{K\beta}+\overline{\beta B})=\cos a\sim\sin a-(\cos b\sim\sin b)=\cos a-\cos b\sim(\sin a-\sin b)=\overline{KC}-\overline{KB}=\overline{KC}+\overline{BK}=\overline{BC}=\overline{2dC}$
$=$[No. 12, § 5] $2\,\overline{\varepsilon E}\times\overline{KD}=$

$$\sim 2\sin\frac{a-b}{2}\left(\cos\frac{a+b}{2}\sim\sin\frac{a+b}{2}\right);$$

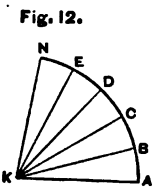
whence

$$\cos a-\cos b=-2\sin\frac{a-b}{2}.\sin\frac{a+b}{2},$$

$$\sin a-\sin b=+2\sin\frac{a-b}{2}.\cos\frac{a+b}{2}.$$

17. Divide the arc AN (Fig. 12) into n equal parts. The radii $\overline{KA}$, $\overline{KB}$, $\overline{KC}$, ..., $\overline{KN}$ are in geometrical progression, but the corresponding arcs are in arithmetical progression, and may therefore be taken for the logarithms of these radii. Put $m\,AN=\log\overline{KN}$, m being the arbitrary modulus; we then have $\log\overline{KN}=m.AN=mn\,AB$. Making n infinity, so

Fig. 12.



that the arc AB may be regarded as a right line perpendicular to KA, we have $\overline{AB}=\sim AB$, or $\overline{AB}=\chi AB$, and $\log\overline{KN}=\chi mn.AB$, or $\log\overline{KN}=mn.\overline{AB}$; for since m is arbitrary, we may substitute m in place of χm. Now $\overline{AB}=\overline{AK}+\overline{KB}=-1+\overline{KN}^{\frac{1}{n}}$; hence

$$\log\overline{KN}=mn\left(-1+\overline{KN}^{\frac{1}{n}}\right),$$

and, putting $KN=1+x$, $\log(1+x)=mn$

$$\left\{-1+1+\frac{1}{n}x+\frac{\frac{1}{n}\left(\frac{1}{n}-1\right)}{2}x^2+\frac{\frac{1}{n}\left(\frac{1}{n}-1\right)\left(\frac{1}{n}-2\right)}{2.3}x^3+\ldots\right\}$$
$$=m\left(x-\frac{x^2}{2}+\frac{x^3}{3}-\frac{x^4}{4}+\ldots\right).$$

18. Let us now divide the two equal arcs AN, AN′ (Fig. 13) into n equal parts; draw the tangent nn' and the secants Kb, Kc, ..., Kn; Kb′, Kc′, ..., Kn′.

We have seen (No. 12, § 4) that, when $\overline{KB}=u$,

$$\frac{\overline{Kb}}{\overline{Kb'}}=u^2,\ \frac{\overline{Kc}}{\overline{Kc'}}=u^4,\ \ldots,\ \frac{\overline{Kn}}{\overline{Kn'}}=u^{2n}.$$

Thus, as before, the quantities

$$\frac{\overline{KA}}{\overline{KA'}},\ \frac{\overline{Kb}}{\overline{Kb'}},\ \frac{\overline{Kc}}{\overline{Kc'}},\ \ldots,\ \frac{\overline{Kn}}{\overline{Kn'}}$$

are in geometrical progression, and the corresponding arcs may be taken for their logarithms, as for example

$$AN=m\log\frac{Kn}{Kn'}.$$

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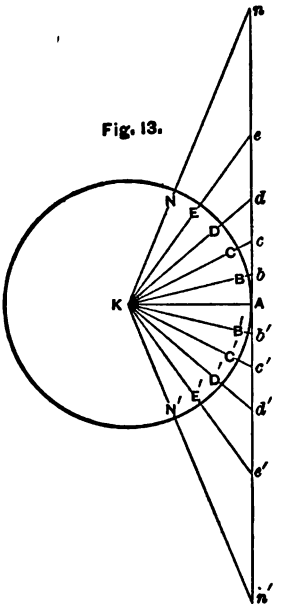
Let $AN=x$, and consequently

$$\overline{Kn}=\overline{KA}+\overline{An}=1\sim\tan x,$$
$$\overline{Kn'}=\overline{KA}+\overline{An'}=1\chi\tan x;$$

Fig. 13.



then we have at once

$$x=m\log\frac{1\sim\tan x}{1\chi\tan x}.$$

But we have seen the arc

$$x=\tan x-\frac{\tan^3 x}{3}+\frac{\tan^5 x}{5}-\ldots;$$

hence

$$m\log\frac{1\sim\tan x}{1\chi\tan x}=\tan x-\frac{\tan^3 x}{3}+\frac{\tan^5 x}{5}-\ldots.$$

Putting $\sim\tan x=z$, this becomes

$$m\log\left(\frac{1+z}{1-z}\right)=\sim\left(z+\frac{z^3}{3}+\frac{z^5}{5}+\frac{z^7}{7}+\ldots\right),$$

or, dividing both members by ~ 1, and noticing that, m being arbitrary, m may be substituted for $\frac{m}{\sim 1}$,

$$m\log\left(\frac{1+z}{1-z}\right)=z+\frac{z^3}{3}+\frac{z^5}{5}+\frac{z^7}{7}+\ldots.$$

19. Resuming the equation

$$x=m\log\frac{1\sim\tan x}{1\chi\tan x},$$

and making $\sim\tan x=z$ as before, let us substitute $\frac{m}{\sim 2}$ for m, or, what is the same thing, make $x=\sim 2x$ in the first member. These changes give

$$\sim 2x=m\log\frac{1+z}{1-z}=\log(1+2z+2z^2+2z^3+\ldots),$$

and

$$\sim 2nx=m\log(1+2z+2z^2+2z^3+\ldots)^n.$$

Now make $\sim 2nx=y$, and suppose n to increase and x to decrease without limit, y remaining constant; $z=\sim\tan x$ will then be infinitely small; hence, in the second member of the development the terms following $2z$ may be omitted, under which supposition the equation reduces to $y=m\log(1+2z)^n$.

The same supposition gives $z=\sim\tan x=\sim x$, $2nz=\sim 2nx=y$, and, therefore, $2z=\frac{y}{n}$. We may then write

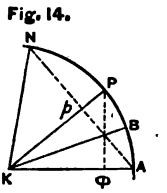
$$y=m\log\left(1+\frac{y}{n}\right)^n$$
$$=m\log\left(1+n.\frac{y}{n}+\frac{n(n-1)}{1.2}.\frac{y^2}{n^2}+\frac{n(n-1)(n-2)}{1.2.3}.\frac{y^3}{n^3}+\ldots\right),$$

and, finally, since $n=\infty$,

$$y=m\log\left(1+y+\frac{y^2}{2}+\frac{y^3}{1.2.3}+\frac{y^4}{1.2.3.4}\ldots\right).$$

20. Suppose the arc AN (Fig. 14) to

Fig. 14.



be divided into an infinite number n of equal parts, of which AB is the first. Take $AP=\frac{1}{2}AN$, and draw AN, KP and $P\varphi$. We have

$$\overline{AB}=\overline{AK}+\overline{KB}=-1+\overline{KN}^{\frac{1}{n}}$$
$$=-1+(\overline{KA}+\overline{AN})^{\frac{1}{n}}=-1+(1+\overline{AN})^{\frac{1}{n}}.$$
$$=-1+1+\frac{1}{n}.\overline{AN}+\frac{\frac{1}{n}\left(\frac{1}{n}-1\right)}{2}.\overline{AN}^2+\frac{\frac{1}{n}\left(\frac{1}{n}-1\right)\left(\frac{1}{n}-2\right)}{2.3}.\overline{AN}^3+\ldots$$
$$=\frac{1}{n}\left(\overline{AN}-\frac{\overline{AN}^2}{2}+\frac{\overline{AN}^3}{3}-\frac{\overline{AN}^4}{4}+\ldots\right)$$

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and $n \cdot \overline{AB} = \overline{AN} - \frac{\overline{AN}^2}{2} + \frac{\overline{AN}^3}{3} - \frac{\overline{AN}^4}{4} + \ldots ;$

whence $n \cdot \overline{AB} = \sim n \cdot AB = \sim$ arc AN, and

$\overline{AN} = 2\overline{pN} =$ [No. 12, §5] $2\overline{\varphi P} \times \overline{KP}$

$$= \sim 2 \sin \frac{AN}{2} \cdot \left(\cos \frac{AN}{2} \sim \sin \frac{AN}{2} \right),$$

or, putting the arc $\frac{AN}{2} = a$, $\overline{AN} = \sim 2 \sin a$ $(\cos a \sim \sin a)$, and therefore

$$\overline{AN}^2 = -(2 \sin a)^2 (\cos 2a \sim \sin 2a),$$
$$\overline{AN}^3 = \chi (2 \sin a)^3 (\cos 3a \sim \sin 3a),$$
$$\overline{AN}^4 = +(2 \sin a)^4 (\cos 4a \sim \sin 4a),$$
$$\overline{AN}^5 = \sim \ldots \ldots$$

Substituting these values in the above series, retaining the medial terms only, since this series is equal to $n.\overline{AB} = \sim 2a$, and dividing by ~ 1, we have

$$2a = 2 \sin a . \cos a + \frac{(2 \sin a)^2 \sin 2a}{2} - \frac{(2 \sin a)^3 \cos 3a}{3} - \frac{(2 \sin a)^4 \sin 4a}{4} + \ldots .$$

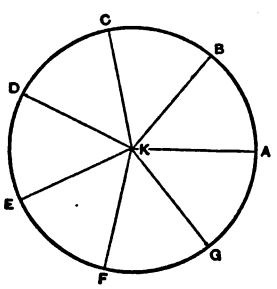
Since the sum of the prime terms must be zero, we have

$$0 = -2 \sin a . \sin a + \frac{(2 \sin a)^2 \cos 2a}{2} + \frac{(2 \sin a)^3 \sin 3a}{3} - \frac{(2 \sin a)^4 \cos 4a}{4} - \ldots ,$$

an equation which may be divided by $2 \sin a$.

21. Divide the circumference (Fig. 15)

Fig. 15.



into n equal parts, AB, BC, . . . GA; n is now a finite quantity. We propose to find the sum S of the mth powers of the radii $\overline{KA}$, $\overline{KB}$, ... $\overline{KG}$.

Let $\overline{KB} = u$, whence $\overline{KC} = u^2$, $\overline{KD} = u^3$, . . . , $\overline{KG} = u^{n-1}$, $\overline{KA} = u^n = 1$; then

$$S = 1 + u^m + u^{2m} + \ldots + u^{(n-1)m},$$

and

$$u^m S = u^m + u^{2m} + \ldots + u^{(n-1)m} + u^{nm};$$

but $u^{nm} = (u^n)^m = 1^m = 1$;

hence $u^m S = S$, and $(u^m - 1)S = o$.

If $u^m = 1$, this is an identical equation, without meaning; but, in this case, $u^{2m} = 1$, $u^{3m} = 1$, . . . ; hence $S = n$. In all other cases $S = o$.

If we denote by P', P'', P''', ... , $P^{(n)}$ the sum of the first, second, ... , nth powers of given quantities, and by Π', Π'', Π''', ... , $\Pi^{(n)}$ the sum of the products of the same quantities taken one and one, two and two, ... , n and n, it is well known that

$$n\Pi^{(n)} = P'\Pi^{(n-1)} - P''\Pi^{(n-2)} + P'''\Pi^{(n-3)} - \ldots \pm P^{(n-3)}\Pi''' \mp P^{(n-2)}\Pi' \pm P^{(n-1)}\Pi' \mp P^{(n)},$$

the upper and lower signs corresponding to the cases in which n is even or odd, respectively. The demonstration of this theorem may be reduced to a simple algebraic transformation. If we apply it to the radii $\overline{KA}$, $\overline{KB}$, ... , $\overline{KG}$, which are n in number, we shall obtain $P' = o$, $P'' = o$, $P''' = o$, ... , $P^{(n-1)} = o$ $P_{(n)} = n$; whence

$$\Pi' = o, \ \Pi'' = o, \ldots ,$$
$$\Pi^{(n-1)} = o, \ n\Pi^{(n)} = \mp n,$$
$$\text{and } \Pi^{(n)} = \mp 1 = -(-1)^n.$$

These properties may also be derived from the equation $x^n - 1 = o$, whose roots are $\overline{KA}$, $\overline{KB}$, ... , $\overline{KG}$.

THE contractors of the St. Gothard Tunnel have applied to the Federal Tribunal to prolong, by seven hundred days, the time originally fixed for the completion of the undertaking. This request is declared to be merely their answer to the company's claim for the enforcement of the penalty of delay (5000 francs a day), and does not signify that the undertaking will not be completed next year. They contend that if the company had done their duty the tunnel would have been finished seven hundred days sooner than is now possible. It is generally well known that the company greatly delayed the contractors.

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THE FLOW OF COMPRESSED AIR THROUGH LONG PIPES.

Experiments at St. Gothard Tunnel, par E. STOCKALPER, Ingenieur Chef de Service.

Translated from Revue Universelle des Mines.

THE differences which exist between the co-efficients in the different works or tables which treat of the flow of compressed air, or permanent gases in long pipes, renders completely uncertain any calculation regarding the loss of charge for a given case.

The greater part of these co-efficients do not coincide with the observations which we have been called upon to make for the delivery of air at the tunnel of St. Gothard. The cause may be referred to the fact, that the experiments which have served to establish these co-efficients have generally been made upon short pipes with low pressures and small volumes of air; that is to say, under conditions not corresponding to the transmission of motive power to long distance.

In order to study the conditions of flow of compressed air, the different factors to be taken into account, are:

1st. The lengths, diameter and nature of the conduit.
2d. The velocity of flow, or the volume of compressed air passing her section through a given section.
3d. The pressures of air at different points along the conduit.
4th. The temperatures in the conduit.

1st. The conduit at St. Gothard tunnel, upon which experiments were made, was composed of—

(*a*). Pipes of cast and of wrought iron of 0.^{m}2 diameter, 4,600 meters long, and with flange and bolt joints enclosing rubber rings.

(*b*). Wrought iron pipes of 0.^{m}15 diameter, 522 meters long, with same joints as above.

(*c*). Wrought iron tubes of 0.^{m}10 diameter and joints as before.

Experiments were not made upon the smaller conduit because of the numerous branchings for delivery upon this portion.

The pipe being practically tight, the losses of air may be neglected in comparison to the amount of air delivered. The bends also need not be taken into account in relation to the total length.

2d. Velocity or volume delivered per second. This was measured by the compressors, which were pumps of the Colladon variety. Their capacity was determined by previous experiments upon a reservoir of 166.50 cubic meters capacity.

3d. The pressures along the conduit were measured by Bourdon gauges measuring to one-twentieth of an atmosphere. For each gauge a correction curve was established by comparing with a standard manometer, a work performed by Prof. D. Colladon, consulting engineer.

4th. The temperatures were taken by thermometers with bulbs inside the conduit, but with their tubes exposed. For these also a correction co-efficient was necessary, as the bulbs were subjected to pressure of the air in the pipe.

In conducting the observations the pressure gauges were applied at eight different points along 5,100 meters of pipe, the furthermost one being at some distance from the branches. Readings were taken every ten minutes.

In order to simplify this account we will regard only the gauges at the principal points—at the points where the diameter changes and at the compressors.

The conditions of different permanent regimens was sought for—that is to say, the relations between certain amounts of air delivered at the terminus, the air furnished by the compressor, and the corresponding constant pressures along the pipe.

These different conditions have been obtained by regulating the work of the compressors or by controlling the delivery at the end of the pipe by aid of regulator cocks.

It is to be regretted that the temperature observations were not made simultaneously with the pressure readings. The thermometers were read at a later period, but it was evident that the re-

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sults of calculations are not influenced by this fact.

The analogy between the flow of water and that of permanent gases, and especially the information afforded by the results of these experiments render it desirable to review here the formulæ for the flow of water in pipes.

The most satisfactory formulæ, whether regarded for their simplicity or their practical utility, are those of Darcy.

A resumé of his formulæ and tables is herewith given:

The tables are based on the assumption that the resistance of friction is given with sufficient exactness by the monomial formula

$$(1)\qquad \frac{DJ}{2}=b_1 u^2$$

in which u is the velocity in meters per second. D=diameter in meters and J=loss of charge per running meter.

The values of b_1 for wrought or cast iron pipes of diameters, between 0.m0122 and 0.m50, are expressed by the formula

$$b_1=0.000507+\frac{0.00001294}{D}$$

From the formula 1 we get

$$D=\frac{2b_1u^2}{J},\qquad J=\frac{2b_1u^2}{D},$$

$$u=\sqrt{\frac{JD}{2b_1}}$$

If Q= the volume delivered per second, then $Q=\frac{\pi D^2}{4}u$ or $u=1.273\frac{Q}{d^2}$

also, $$Q=\frac{\pi}{4}\sqrt{\frac{JD^5}{2b_1}}\qquad D=\sqrt[5]{\frac{32Q^2b_1}{\pi^2J}}=$$

$$=\sqrt[5]{3.2423\frac{b_1Q^2}{J}},$$

$$J=3.2423\frac{b_1}{D^5}Q^2$$

Representing the value of the co-efficient of Q^2 by a, this last formula becomes $J=aQ^2$

whence also

$$a=\frac{J}{Q^2}\text{ and }Q=\sqrt{\frac{J}{a}}$$

These formulæ are applicable to either drawn or cast iron pipes.

The following table contains the values of a for different values of D, deduced from Darcy's experiments:

Diameters D.	Values of a.	Diameters D.	Values of a.	Diameters D.	Values of a.
0,01	58395000,	0,18	9,918	0,39	0,194055
0,02	1169250,	0,19	7,5295	0,40	0,17067
0,027	222800,	0,20	5,7855	0,41	0,15056
0,03	125155,	0,21	4,50925	0,42	0,133225
0,04	26280,5	0,216	3,90305	0,43	0,118435
0,05	7937,	0,22	3,5546	0,44	0,10538
0,054	5267,5	0,23	2,8361	0,45	0,094005
0,06	3010,45	0,24	2,2805	0,46	0,08422
0,07	1333,05	0,25	1,8526	0,47	0,075495
0,08	660,95	0,26	1,51725	0,48	0,067825
0,081	619,3	0,27	1,2518	0,49	0,06118
0,09	356,905	0,28	1,0418	0,50	0,055195
0,10	206,21	0,29	0,8710	0,55	0,034114
0,108	138,135	0,30	0,73385	0,60	0,0220155
0,11	125,625	0,31	0,6206	0,65	0,0146985
0,12	80,005	0,32	0,52855	0,70	0,010128
0,13	52,92	0,325	0,488235	0,75	0,0071595
0,135	43,529	0,33	0,45235	0,80	0,005175
0,14	36,111	0,34	0,388915	0,85	0,00381445
0,15	25,3195	0,35	0,33521	0,90	0,00286075
0,16	18,1505	0,36	0,29063	0,95	0,00173075
0,162	17,0285	0,37	0,252955	1,00	0,00168275
0,17	13,313	0,38	0,221375		

For pipes in actual use it is necessary to double the values of a found in the table.

The fundamental formulæ for the flow of permanent gases are derived from the differential equation afforded by the mechanical theory of heat.

Under the hypothesis that during the

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flow of the compressed air, heat is neither added nor abstracted, the following formulæ are deduced:

$$3\ \begin{cases} \dfrac{u_2^2}{2g} = \dfrac{C}{A}(T_1 - T_2) \\ \dfrac{T_2}{T_1} = \left(\dfrac{p_2}{p_1}\right)^{\frac{k-1}{k}} \end{cases}$$

In which

u_2 = final velocity in meters for second.
g = 9.81.
C = 0.2377 specific heat of air.
$\frac{1}{A}$ = 436 mech. equivalent of heat.
$T_2 = 273 + t^\circ_2$ absolute final temperature.
$T_1 = 273 + t^\circ_1$ absolute initial temperature.
k = 1 41.
p_1 = pressure in kilos. per sq. meter beginning of conduit.
p_2 = pressure at extremity of conduit.

The hypothesis is strictly correct only for a conduit which will not conduct heat.

The above formulæ indicate that the temperature of the air in the pipe is lowered in the same proportion as the air expands; or, in other terms, the heat diminishes in the same proportion as the pressure in the conduit.

Under the hypothesis that the gas is maintained at a constant temperature, we have the equation

$$(4)\quad \frac{u_2^2}{2g} = \text{R.T. nat. log}\frac{p_1}{p_2}$$

in which T is the absolute temperature and R is the constant of Mariotte and Gay-Lussac, which for air is 29,269.

This hypothesis assumes that heat is added, during the flow through the pipe, in quantity to supply the loss due to expansion.

Evidently, neither of these hypotheses is exactly realized in the practical application, but it is proper to determine by trial which best represents the real conditions, and so determine which is best to accept as a basis for calculation. For a practical beginning of the problem, the following thermometric experiments were made in the conduit. Thermometers were inserted along the conduit at different points. Upon each a series of observations were made at different days, the velocity varying from 4 to 12 meters and the pressure from 3 to 6 atmospheres. At the same time the temperature of the air outside the conduit was taken at each point, this being the temperature of the tunnel and constant for each point.

The observations made show that notwithstanding the variation of velocity and pressure, the temperature of the compressed air remained practically the same for each point, varying not more than half a degree; and that from point to point advancing into the tunnel it increased with the temperature of the tunnel.

Omitting the observations near the entrance where the temperature is variable, and beginning at a point 800 meters within the tunnel, it was found that the temperature of the compressed air was about three degrees below the temperature of the air of the tunnel at each point.

It was concluded that owing to the feeble calorific capacity of air, and the high conducting qualities of metal pipes, that compressed air will take, in long conduits, practically the same temperature as the surrounding medium.

In general, therefore, the medium traversed by the conduit being constant, formula 4, established under the last hypothesis, is best adapted for general application.

To facilitate calculations this may be somewhat modified.

We may write

$$\text{Nat. log.}\frac{p_1}{p_2} = \text{nat. log.}\frac{p_2 + p_1 - p_2}{p_2} = \text{nat. log.}\left(1 + \frac{p_1 - p_2}{p_2}\right).$$

Remembering that

$$\text{nat. log. } (1+\chi) = \chi - \frac{\chi^2}{2} \ldots$$

we shall have, taking only the first term:

$$\text{nat. log.}\frac{p_1}{p_2} = \frac{p_1 - p_2}{p_2}$$

consequently

$$(5)\quad \frac{u_2^2}{2g} = \text{RT}\frac{p_1 - p_2}{p_2}\ *$$

Let now the density of the air or its weight per cubic meter be introduced.

* This equation is the one used in calculations. By writing p_1 for p_2 in the denominator, and introducing a coefficient of friction z, and admitting that friction is proportional to the square of the velocity, also directly as the length and inversely as the diameter of the pipe, we have:

$$\frac{u^2}{2g} = \text{RT.} = \frac{zL}{D} \cdot \frac{p_1 - p_2}{p_1}$$

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We know that for permanent gases

$$\frac{p\,v}{T} = R, \text{ a constant}$$

v = the volume of a unit weight.
δ = density; wt. per meter cube,

then $$v = \frac{1}{\delta}$$

and $$\frac{p}{\delta T} = R$$

consequently $$\frac{RT}{p_2} = \frac{1}{\delta_2}$$

Substituting in eq. (5) it becomes

$$\frac{u_2^2}{2g} = \frac{p_1 - p_2}{\delta_2}$$

In this equation if we use the mean values of velocity, density and temperature by taking

$$u = \frac{u_1 + u_2}{2}$$

$$\delta = \frac{\delta_1 + \delta_2}{2}$$

and $$T = \frac{T_1 + T_2}{2}$$

we shall have

$$(6) \qquad \frac{u_2}{2g} = \frac{p_1 - p_2}{\delta}$$

No account has yet been taken of the loss due to friction. The diminution of pressure serves not only to increase the velocity—it should also aid in diminishing friction. In the case of water, Darcy's experiments have shown that it is sufficiently exact to assume that the frictional resistance is simply proportional to the square of the velocity, instead of the more complex value of $au + bu^2$. We may readily admit the same hypothesis for air, with less liability of error where the resistance to friction is less and the velocities in general are greater.

If we express this resistance by zu^2 the formula (6) becomes

$$\frac{u^2}{2g} + zu^2 = \frac{p_1 - p_2}{\delta}$$

$$\left(\frac{1}{2g} + z\right) u^2 = \frac{p_1 - p_2}{\delta}$$

in which the factor in parenthesis is a co-efficient constant for each pipe and for each diameter D, a co-efficient which, from analogy with resistances of water, we may place equal to

$$\frac{2b_1}{D} l$$

in which l is the length of the conduit.

We shall then have

$$\frac{2b_1}{D} l u^2 = \frac{p_1 - p_2}{\delta}$$

Calling J the difference of pressure $p_1 - p_2$ per running meter, we shall have

$$\frac{2b_1}{D} u^2 = \frac{J}{\delta}$$

Using a function of the volume Q in place of the velocity v

$$Q = \frac{\pi D^2}{4} u$$

$$u^2 = \frac{16}{\pi^2} \frac{Q^2}{D^4}$$

By substitution it becomes

$$3.2423 \frac{b_1 Q^2}{D^5} = \frac{J}{\delta}$$

in which Q is the mean volume and

$$= \frac{Q_1 + Q_2}{2}.$$

Taking as Darcy does

$$\frac{3.2432\, b}{D^5} = a_1,$$

we shall have the formula under its final form.

$$(7) \quad \begin{cases} J = a_1 Q^2 \delta \\ a_1 = \dfrac{J}{Q_2^2 \delta} \\ Q = \sqrt{\dfrac{J}{a_1 \delta}} \end{cases}$$

in which the density

$$\delta = \frac{p}{RT}$$

This formula (7) is quite analogous to Darcy's formula given above for the flow of water. For the density of water being constant whatever the pressure, the value of δ is unity; but if we take $\delta = 1000$ the previous formula would have given

$$J = \frac{a}{1000} Q^2 \delta$$

the value of the numerical co-efficient of a.

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The complete analogy between the formulæ suggests, that taking the influence of the density into account $\frac{a}{1000}$ be substituted for a, the latter being the co-efficient for water employed in Darcy's tables.

$$a_1=\frac{a}{1000}$$

is employed in the following calculations.

(Experiments made Dec. 17th, 1878, at St. Gothard Tunnel, north side).

The quantity of air during the first set of trials, was

$v_0=0.936$ cubic meters per second,

measured at 0°C, and average atmospheric pressure at Paris.

1st. For the pipe 0.^{m}20′ diameter and 4,600 meters length, the pressure at the entrance

$p_1=5.66$ atmospheres

at 4,600 meters $p_2=5.24$ "

The loss of pressure was 0.36 atmospheres.

The mean pressure was 5.42 atmospheres.

The mean temperature, being that at the middle point, was $t=21°$; hence T=294°.

The volume delivered per second under these conditions should be

$$Q=\frac{v_0}{p}(1+0.00366\times t)=0.185$$

cubic meters.

For water, Darcy's table gives when D=0.20 and $a=5.785$, the loss of pressure per running meter,

$$J=aQ^2=5.785\times\overline{0.185}^2=0.198;$$

and the loss for length of 4600 meters $p_1-p_2=0.198\times4600=910$ meters, head of water.

For air the loss would be

$$p_1-p_2=\frac{910\times\delta}{1000}\text{ in which }\delta=\frac{p}{RT}$$

$$\text{kilos. per sq. meter}=\frac{5.42\text{ atm.}\times10334}{2.93\times294}$$

$$=6.^k500.$$

This substituted above gives:

Loss of charge in head of water

$$p_1-p_2=\frac{910\times6.500}{1000}=5.^m91$$

$$\text{in atmospheres}=\frac{5.91}{10.334}=0.57$$

atmospheres

calculated loss = 0.57 atmospheres
observed loss = 0.36 "
Difference 0.21 "

Loss of pressure on second section of the conduit, diameter of 0.^{m}15 and length 522 meters,

$p_1=5.24$ atm.; $p_2=5.00$,

loss observed = 0.24 atmospheres.

Mean temperature

$t=26.5$, T=299.5 $p=5.12$

$$Q=\frac{0.936\ (1+0.00366\times26.5)}{5.12}=0.20$$

For water

when D=0.15 $a=25.32$
$J=aQ^2=1.01$

per running meter. For 522 meters = 527.22 meters, head of water.

For air this becomes

$$p_1-p_2=\frac{527.22\times\delta}{1000}$$

$$\text{but}\quad\delta=\frac{5.12\times10334}{29.3\times299.5}=6.^k03$$

$$\text{hence}\quad p_1-p_2=\frac{527.22\times6.03}{1000}=3.^m18$$

of water

$$=\frac{3.18}{10.334}=0.30\text{ atmospheres.}$$

The loss observed was 0.24
Difference = 0.06 atmospheres.

SECOND SET OF EXPERIMENTS.

During this series, the volume of air, at standard temperature and pressure, was:

$v_0=0.623$ cubic meters per second.

Loss of pressure in the larger pipe was, by observation:

$p_1=4.35$
$p_2=4.13$
$p_1-p_2=0.22$ atmospheres.

mean pressure = 4.285

mean temperature, $t=21°$, T=294

hence, Q=0.156 cub. meters.

For water this would be:

D = 0.20, $a=5{,}785$,

and $J=aQ^2=0.1408$ per running meter; and for 4,600 meters:

$p_1-p_2=647.68$ meters of head.

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For air this becomes:

$$p_1 - p_2 = \frac{647.68 \times \delta}{1000}$$

but $\delta = 5^k.14$

hence $p_1 - p_2 = 3.329$ meters head of water.

$$= \frac{3.329}{10.334} = 0.32 \text{ atmospheres.}$$

Loss of pressure
observed = 0.22 "
Difference = 0.10 "

Loss of pressure in second section of pipe. Diameter, $0^m.15$; length, 522 meters.

$p_1 = 4.13$
$p_2 = 4.06$
loss $= 0.07$ atmospheres.

mean pressure $= 4.095$
$t = 26.5$, T $= 299.5$

whence Q is found to be 0.166 cu. meters.

For water:

when D $= 0.15$ $a = 25.32$

$J = a\,Q^2 = 0.6977$ per running meter.

For 522 meters $= 364.20$ meters head of water.

For air:

$$p_1 - p_2 = \frac{364.20 \times \delta}{1000}$$

$$\delta = \frac{4.095 + 10334}{29.3 \times 299.5} = 4.82$$

hence $p_1 - p_2 = 1.75$ meters head of water.

$$= \frac{1.75}{10.334} = 0.17 \text{ atmospheres.}$$

Loss observed, $= 0.07$
Difference, $= 0.10$ atmospheres.

THIRD SET OF EXPERIMENTS.

During this series the volume of air, measured under standard conditions of temperature and pressure was $v_0 = 0.520$ cub. meters per second.

In the larger pipe, $p_1 = 3.84$
$p_2 = 3.65$
loss, $p_1 - p_2 = 0.19$ atmospheres.

Mean pressure $= 3.745$ atm.
$t = 21°$, T $= 294$
Q $= 0.149$ cub. meters.

For water:

when D $= 0.20$. a 5.785
J $= a\,Q^2 = 0.127$

and for 4600 meters $= 584.2$ meters head.

For air:

$$p_1 - p_2 = \frac{584.20 - \delta}{1000}$$

but $\delta = 4^k.49$

hence $p_1 - p_2 = 2.62$ meters head of water.

$$= \frac{2.62}{10.334} = 0.25 \text{ atmospheres.}$$

Loss observed, $= 0.19$
Difference, $= 0.06$ atmospheres

Loss of pressure in second section of pipe:

$p_1 = 3.65$ atm.
$p_2 = 3.545$ "
loss, $p_1 - p_2 = 0.105$ "

Mean pressure $= 3,597$
$t = 26.5°$ T $= 299.5$
Q $= 0.158$ cubic meters.

For water this would be:

when D $= 0.15$ and $a = 25.52$
J $= a\,Q^2 = 0.632$

for a length of 522 meters

$p_1 - p_2 = 329.90$.

For air this becomes

$$p_1 - p_2 = \frac{329.90 \times \delta}{1000}$$

$$\delta = 4.^k23$$

hence $p_1 - p_2 = 1.395$ meters of water.

$$= \frac{1.395}{10.334} = 0.135 \text{ atmospheres}$$

loss observed $= 0.105$
difference $= 0.03$ atmospheres.

In the application of these principles there may be considered as given the quantity Q or the velocity u, the pressure p_1 and the temperature t_0 as data for calculating the approximate loss of pressure. The result for given cases would be arrived at by successive approximations.

To compare the above results with those obtained by using the formulæ generally employed to calculate the loss of pressure during the flow of gases, we will review these formulæ, preserving the above notation.

The best known formula is

$$p_1 - p_2 = \varphi \cdot \frac{l}{D} \cdot \frac{p}{RT} \cdot \frac{u^2}{2g}$$

in which

$$\frac{p}{RT} = \delta$$

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and consequently

$$p_1 - p_2 = \varphi \cdot \frac{l}{D} \cdot \delta \cdot \frac{u^2}{2g}$$

in which, according to Girard, D'Aubuisson or Pecquer, φ should be taken

$$= 0.024,$$

and according to Weisbach,

$$= \frac{0.12}{\sqrt{u}}.$$

Morin's formula is

$$p_1 - p_2 = \frac{u^2}{2g}\delta\left(1 \pm 0.0252\frac{l}{D}\right).$$

Arson has prepared tables from the formula

$$p_1 - p_2 = \frac{4l}{D}\delta(au + bu^2)$$

in which for the pipes above considered

D=0.^{m}20, a=0.00033, b=0,000395
D=0.^{m}15, a=0.00044, b=0,000430

The above formulæ express the loss of pressure in kilogrammes per sq. meter, which, for the sake of comparison with the results above obtained, will be reduced to atmospheres by dividing by 10334.

Applying these different formulæ the results, as exhibited in the following table, are obtained :

	Diameter.	Length.	Cor. vol. v_0.	Mean pressure.	Mean temperature.	Wt. per cubic meter.	Q.	Mean velocity.	Loss of pressure.				
									Observed.	Calculated.			
										$J = aQ^2b$.	d'Aubuisson, etc.	Morin.	Arson.	Weisbach.
	M.	M.	M^3.	Atm		Kil.	M^3.	M.						
First Series.....	0,20	4600	0,936	5,42	21°	6,500	0,185	5,89	0,36	0,57	0,61	0,64	0,90	1,25
	0,15	522	0,936	5,12	26,5	6,030	0,200	11,32	0,24	0,30	0,31	0,34	0,48	0,46
Second series.....	0,20	4600	0,623	4,285	21	5,140	0,156	4,968	0,22	0,32	0,345	0,30	0,52	0,76
	0,15	522	0,623	4,095	26,5	4,820	0,166	9,394	0,07	0,17	0,175	0,15	0,27	0,29
Third series..... ..	0,20	4600	0,520	3,745	21	4,490	0,149	4,747	0,19	0,25	0,27	0,29	0,41	0,63
	0,15	522	0,520	3,597	26,5	4,230	0,158	8,942	0,105	0,135	0,14	0,15	0,22	0,28

From an inspection of the table, the following conclusions are readily drawn :

1st. The losses of pressure calculated by the formulæ, are sensibly greater than the observed amounts.

2d. That the co-efficient of Morin is probably derived from the experiments of d'Aubuisson and Girard.

3d. That Weisbach gives too high values, especially for low velocities.

4th. That although the co-efficients of Arson have been derived from the most precise experiments, they nevertheless give too small values for loss of pressure under the conditions of the above experiments.

This fact is probably due to the low pressures at which his experiments were conducted; only 0.^{m}14 of water at the maximum, and for the purpose of distributing illuminating gas.

5th. That our formula employing the co-efficients of Darcy, gives results more nearly according with observation than any of the others.

It is to be regretted that we have not the results of the experiments made in 1852 by Prof. Colladon, to compare with the above list.

In an address delivered in June, 1857—an address which led the Chamber to decide upon tunneling Mont-Cenis, Gen. Menabrea said :

"The honor of having suggested this rational idea belongs to Prof. Colladon, of Geneva. He proposes to drive the drilling machines, not by cords and pulleys, but by compressed air."

He added : "The experiments of M. Colladon have proved that air, when conducted through pipes, meets with much less resistance than some writers

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have supposed; this resistance being the obstacle which has led to serious doubt whether air could be conveyed long distances and preserve its elastic force."

We find in a publication of M. Hudry-Menos in 1871, entitled "Le Tunnel des Alpes," an approximate statement of the result attained by M. Colladon:

"The transmission of compressed air to great distances was the fine achievement of the great enterprise. . . . . M. Colladon, fortified by numerous experiments in 1852, upon a pipe 0.^{m}25 in diameter and 700 meters long, announced in a memoir accompanying his demand for a patent, that tbe co-efficients of resistance, adopted up to that time for the movement of gases in smooth conduits, was too high and should be reduced to about one-half."

We may state here that our experiments confirm the conclusions announced in 1852 by M. Colladon, in the sense that the losses of pressure which we have observed are about two-thirds of the amounts deduced from the formulæ of Girard and d'Aubuisson, and about one-half those of Arson.

In this article we have shown theoretically that the loss of pressure in air conduits may be written like that for water conduits under the form,

$$J = a_1 Q'^2 \delta,$$

and our experiments justify the conclusion that for practical purposes the co-efficient a_1 is the same for air as for water, or in other words, to calculate the loss of charge in an air conduit, it will suffice to estimate the loss as though it were water moving with the same velocity, and then to reduce the result found by the ratio of the density of compressed air to the density of water.

If the experiments upon which these conclusions are based, do not exhibit the precision of a physical experiment, a precision which the means at our disposal and the regular routine of the work would not permit us to attain, we believe that, considering the great length of the conduit, the amount of the pressures, the quantity and velocity of the air, and the duration of the observations, that these investigations present the character of thoroughly practical experiments.

THE PRINCIPLES INVOLVED IN THE CONSTRUCTION OF THE TELESCOPE.

By THOMAS NOLAN, B. S.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

II.

II. THE REFLECTING TELESCOPE.

Having considered the principles on which the simple refracting telescope is constructed, we will next explain the manner in which the properties of the reflection of light are utilized for astronomical observation by the reflecting telescope.

An image may be formed by reflection from a polished surface, wrought into a regular convexity, on the same principles of the divergence and convergence of the reflected rays, as by refraction through polished transparent surfaces.

If rays of light, falling upon a concave mirror, diverge from a point beyond the center of curvature, they will converge, after reflection, to a point between the principal focus, or focus for parallel rays, and the center of curvature. This point is called the conjugate focus.

If light radiates from L (Fig. 8), it is reflected to l; if it radiates from l, it meets at L. If the radius of the mirror and the distance of one focus from it are given, the distance of its conjugate focus may be determined. As the angle L$K l$ is bisected by the radius KC, we have LK : lK :: CL : lC—that is, when KA is considered very small, LA : lA :: CL : lC, or, letting r=radius, LA : lA :: LA—r : r—lA. Hence, $LA = \frac{r \cdot lA}{2lA - r}$, and $lA = \frac{r \cdot LA}{2LA - r}$. If the luminous point is at C, all the rays will be "reflected back"

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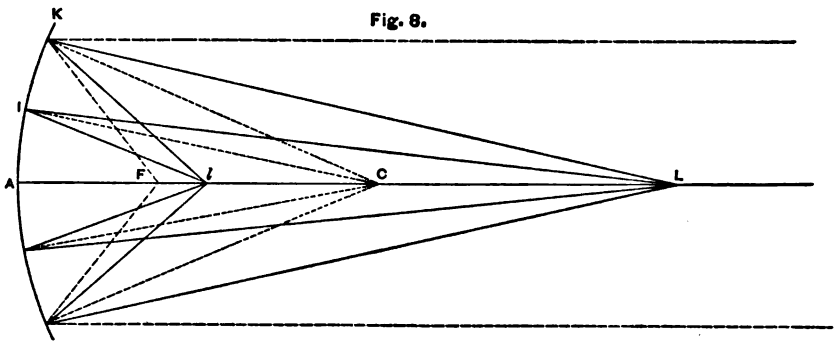
to the same point, and while the radiant point moves from C to infinity, the conjugate focus moves from C to F,—the principal focus.

Although there are many cases arising from the reflection of light at curved surfaces, due to position of mirror and direction of incident rays, it will be sufficient for our purpose to consider those particular cases of reflection which are involved in the construction of the various forms of the reflecting telescope.

Fig. 8.

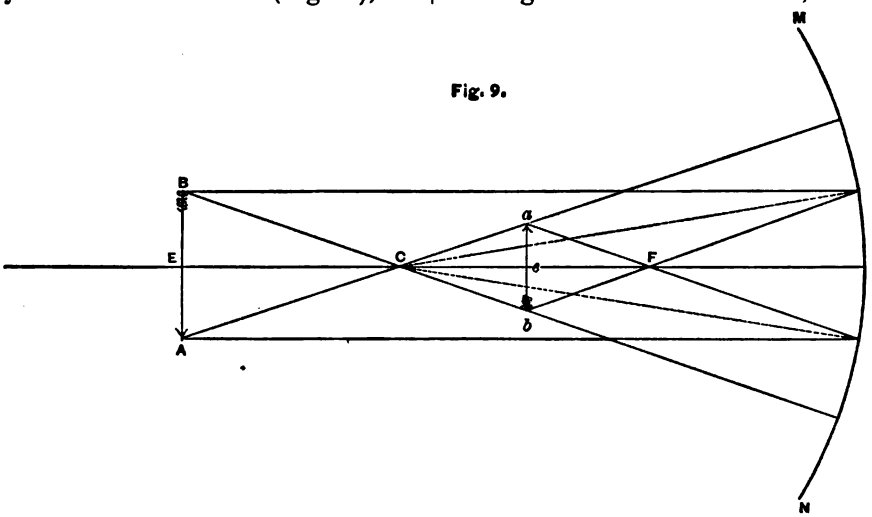


By an examination of (Fig. 9), the formation of an image by a concave mirror is easily understood. The rays AC*a* and BC*b* from the object AB passing through the center of curvature C, fall perpendicularly on the surface MN, and are "reflected back" on themselves, so that the focus of the point A is somewhere on A*a*, and that of B on B*b*. By drawing another ray from A, we find it reflected to *a*, which is the focus of A; and by drawing another ray from B, we find it reflected to *b*, the focus of B.

Since A*a* and B*b* cross at C, *ab* is smaller than AB, as *e*C is smaller than EC. When the object is a heavenly body, it is at a practically infinite distance, and the rays are parallel, and the image found half-way between the mirror and its center of curvature.

In regard to the convex mirror, the only case which happens in the reflecting telescope is that of converging rays incident upon a surface of such convexity as to render them less convergent.

Fig. 9.



In (Fig. 10) we consider the light, after having been reflected from some converging surface, to proceed to the con-

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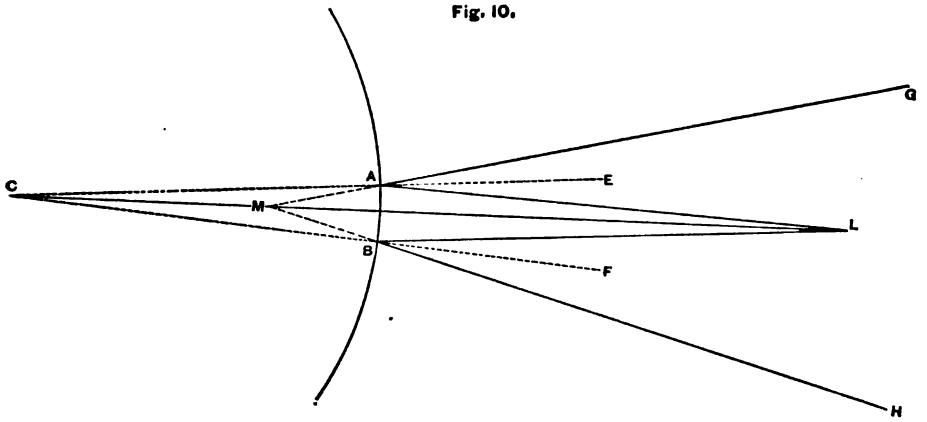
vex mirror along the lines GA and HB, towards some point M. These rays, after reflection converge to L, and come to a focus in front of the mirror, at a point further in front than its center C is behind it, so that they have been rendered less convergent.

bisects the angle EC*c*, between the axis of the tube and a line C*c* from its center to the edge of the opening of the tube. Parallel rays, falling on AD, are reflected to the side of the tube, where the image is formed, and where the eye-glass is placed to magnify it. The image *ob*

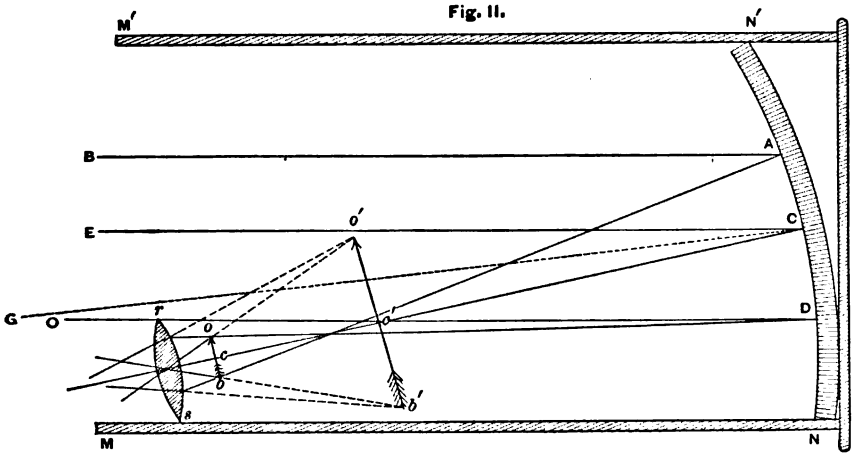
Fig. 10.



As the image formed by the concave speculum of a telescope is on the same side as the object, some arrangement is necessary to prevent the observer's head obstructing the passage of light to the speculum, and hence we have

is represented as being magnified by a single convex lens *rs*. As it falls between *rs* and its principal focus, a second, and enlarged, image is formed at *o'b'*. While the Herschelian has the brightest image of all the reflecting telescopes,

Fig. 11.



1. FOUR DIFFERENT FORMS OF THE REFLECTING TELESCOPE.

(1). *The Herschelian Telescope.*—In this instrument the speculum is so tilted as to bring the image to one side of the tube. The concave reflector AD (Fig. 11) is fixed at the bottom of the tube MN M'N', and tipped so that its axis GC

with a given aperture, and possesses the advantage—so thoroughly appreciated by those in the habit of observing for many consecutive hours—of allowing the observer always to look downward, its disadvantages are still many. It cannot produce the finest definition, because the reflecting surface cannot bring the rays to an exact focus when they are thrown

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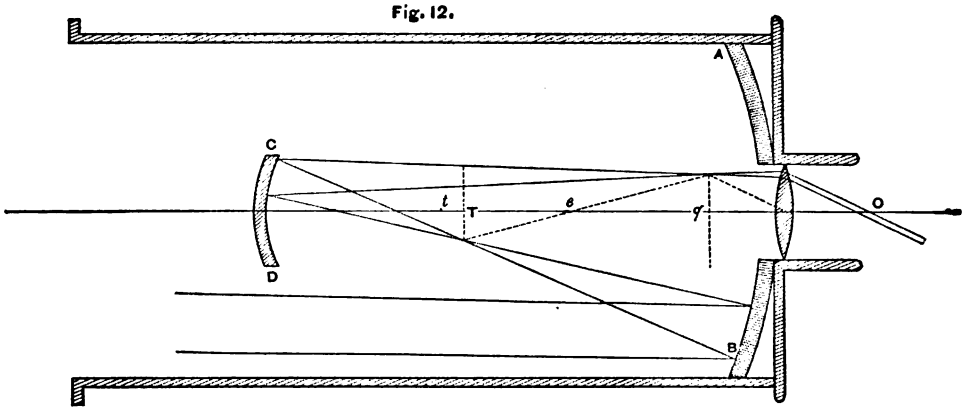
so far to one side of the axis of the tube; and the injury to definition, on this account, is so great that the "front view" plan has been almost entirely abandoned.

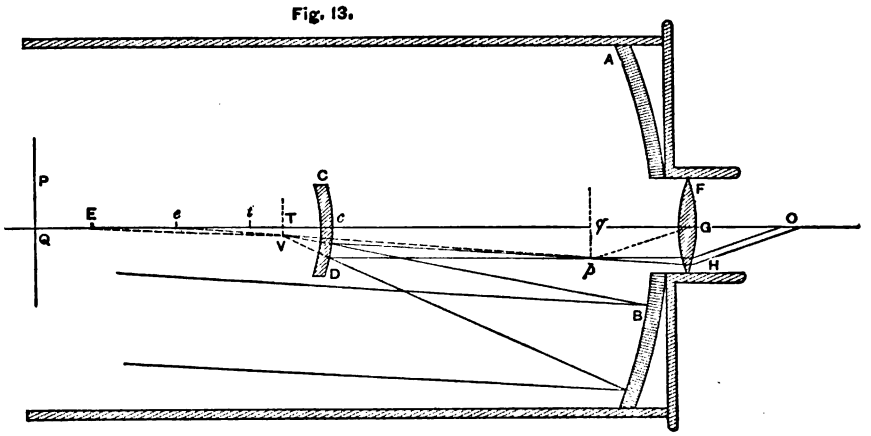
(2). *The Gregorian Telescope.*—The general principle of this construction is shown in (Fig. 12). AB is the speculum. A little beyond the image T, which is formed in the axis OT, is a small concave mirror CD. T is, with regard to CD, as an object placed between its focus *t*, and its center *e*; and CD forms a second image *q*, more or less distant from *e* as T is nearer to, or more remote from *t*. By moving CD nearer to, or further from T, *q* may be carried to any distance. The latter is commonly brought a little in front of AB, in which is an aperture, through which, by means of a proper eye-glass, *q* is viewed. The image appears erect, being reversed with regard to T, which is itself reversed with respect to the object.

Fig. 12.



(3). *The Cassegrainian Telescope.*—In this construction the smaller reflector CD (Fig. 13) is convex, and so placed that the image T falls between CD and its principal focus *t*. If CD be removed, and the axis GcE directed to Q in the object PQ, an inverted image TV, terminated by the lines QET and PEV, is formed in the principal focus of AB. But if CB be replaced the rays are intercepted by it before they reach T, and since TV falls between the surface CD, and its principal focus *t*, an erect image *qp* of TV is formed, and is terminated by the lines *e*T*q* and *e*V*p*. This image is viewed through the lens FGH, whose focal length is G*q*.

Fig. 13.



Objects appear inverted, for *pq*, which

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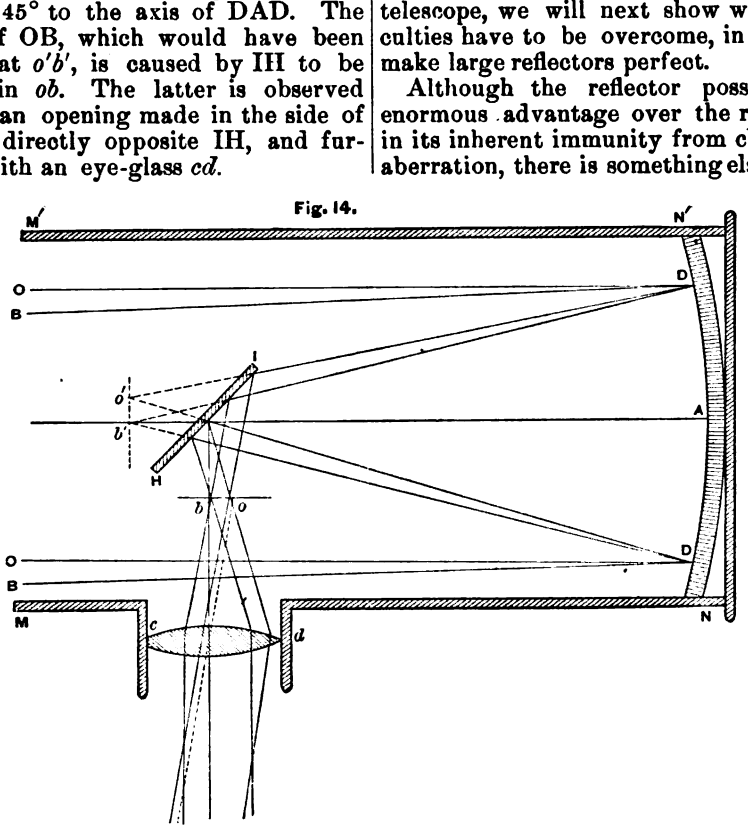
is erect with respect to TV, or inverted with respect to PQ, is in or near the principal focus of FGH; the image upon the retina is, therefore, erect, and consequently the object will appear inverted.

(4). *The Newtonian Telescope.* — A representation of this telescope is given in (Fig. 14), in which DAD is a concave speculum, and IH a small plane mirror, inclined 45° to the axis of DAD. The image of OB, which would have been formed at *o'b'*, is caused by IH to be formed in *ob*. The latter is observed through an opening made in the side of the tube directly opposite IH, and furnished with an eye-glass *cd*.

Fig. 14.



If we let PQ (Fig. 15) be the object, *pq* its image, *nm* the image formed by the plane surface IcH, and *klr* a convex ey-eglass, whose focal length is *ln;* then *mn*, equal to *pq*, and corresponding to QP, is seen through *klr*, under the angle *mln*; and QP is seen, with the naked eye placed at the center E, under the angle *qEp*. Since these angles have equal subtenses—*mn* and *qp*—they are to each other inversely as *ln* and E*q*, and, consequently, the angle which the object subtends at the center of the eye, when viewed with the telescope, is to the angle when viewed with the naked eye, as E*q* is to *ln*—that is as the focal length of the speculum is to that of the eye-glass. The fraction $\frac{Eq}{ln}$ is, therefore, the measure of the *magnifying power* of this telescope.

Having explained the optical principles underlying the construction of the most common forms of the reflecting telescope, we will next show what difficulties have to be overcome, in order to make large reflectors perfect.

Although the reflector possesses an enormous advantage over the refractor, in its inherent immunity from chromatic aberration, there is something else which quite lowers its position with regard to the latter, and that is,

2. SPHERICAL ABERRATION BY REFLECTION.

That all light falling in parallel lines on a concave spherical surface is reflected to a focus, is true only in a general sense. In (Fig. 16) MI is a section of a speculum, whose center of curvature is L, and DC, EG and HI, incident parallel rays. To find the focus of EG we draw LG, and make the angle FGL equal to EGL. But in repeating the process for HI it is reflected to K, and the further the rays from DC, the further from F is the light

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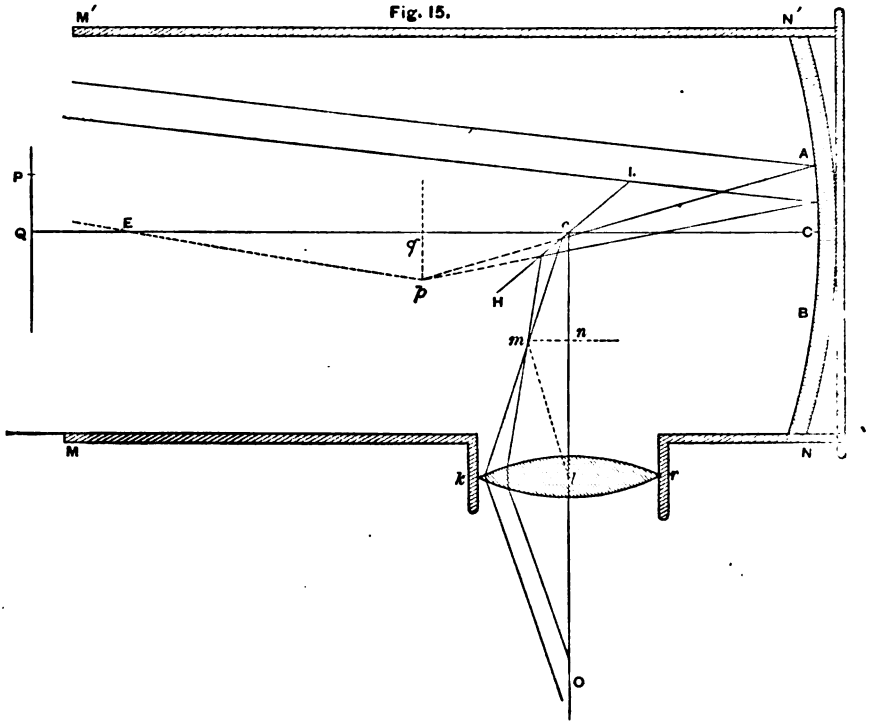
Fig. 15.



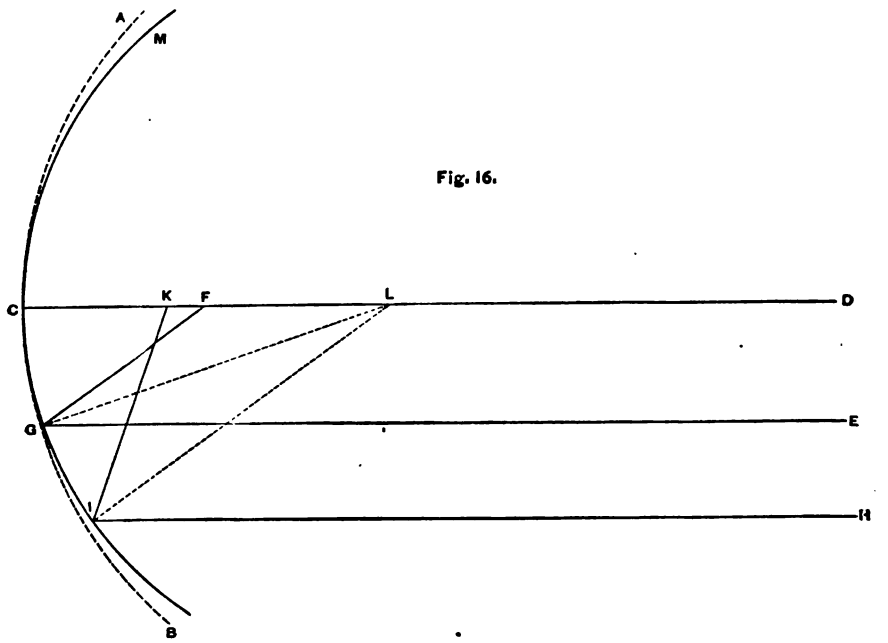


Fig. 16.

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reflected. The edges of MI must, therefore, be thrown back to ACB, which makes its margin a part of a less concave speculum, and throws its focus further from itself, to F instead of to K. It is evident that this curve, which will throw all the parallel rays to one point, is the parabola; and the speculum, especially when of large diameter, is of no use without an *approximate* parabolic curve.

It is in the *polishing* of specula that the curve is altered from the spherical to the parabolic form, and it is here that the finest niceties of manipulation come into play, and the utmost skill and patience are required. That it is extremely difficult to give the parabolic figure, may be gathered from Sir John Herschel's statement, that in the case of a speculum 48 inches in diameter, and 40 feet in focal length, the distance between the spherical and parabolic surfaces at its edges was $\frac{1}{21333}$ of an inch.

In regard to the form of specula, it may be stated generally, that that is a good form which gives a good image; and that the geometrical distinctions between the sphere and parabola become mere theoretical abstractions in the figuring and polishing of specula, there being no practical mode of ascertaining, by any system of measurements on a scale, *what* form the surface has, apart from the optical effect on the rays of light.

III. THE COMPOUND REFRACTING, OR MODERN APLANATIC AND ACHROMATIC TELESCOPE.

In discussing the simple refracting telescope, it was assumed that spherical lenses bring rays of light, issuing from a point, to a focus without *dispersion*. But where the greatest accuracy is required, it becomes necessary to consider the imperfections of spherical lenses, and to discuss the subjects of *spherical* and *chromatic aberrations*, upon a perfect understanding of which the construction of the modern refractor depends.

1. THE "OBJECTIVE."

(1). *Spherical Aberration by Refraction.*—If the diameter of the lens VW (Fig. 17) is large in proportion to its radius of curvature, parallel rays are not brought to an accurate focus, but while the central rays cross the axis at F, the extreme rays intersect it at G, and intermediate rays at points between F and G. To

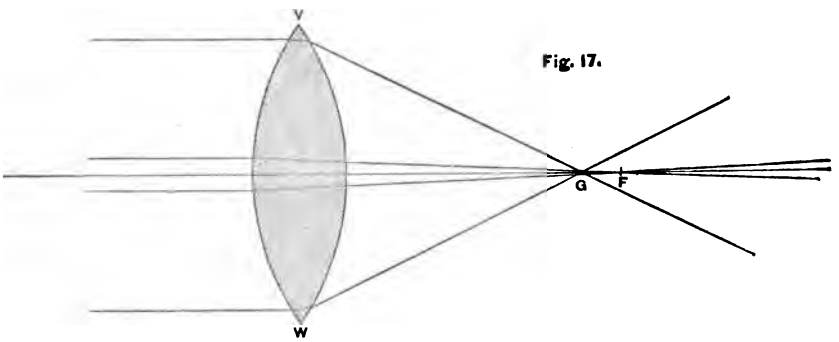

Fig. 17.

estimate the amount of spherical aberration in any case,* we calculate the course of a ray falling upon the border of the lens. AC (Fig. 18) is a section of the curved refracting surface, and QCq its axis. The refractive index is n. The distance QC, of the radiant point, is given, and also CD and AD co-ordinates of the point A. Hence, the normal AE and sub-normal DE may be found. Aq is the refracted ray required, cutting QCq in q.

sin incidence : sin AEC : : QE : QA.

sin E : sin refraction : : qA : qE.

$\therefore$ sin incidence : sin refraction

$$: : n : 1 : : \frac{qA}{qE} : \frac{QA}{QE},$$

* *Microscopical Journal*, Vol. VIII., p. 21.

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$$\therefore \quad \frac{qA}{qE} = \frac{n \cdot QA}{QE} = c \text{ (a known quantity).}$$

$\overline{qA}^2 = c^2 . \overline{qE}^2$, that is,

$$\overline{qE}^2 + \overline{EA}^2 + 2qE \cdot ED = c^2 \cdot \overline{qE}^2,$$

$$\therefore (c^2-1)\overline{qE}^2 - 2ED \cdot qE = \overline{EA}^2.$$

$$\therefore \overline{qE}^2 - \frac{2ED}{c^2-1} \cdot qE = \frac{\overline{EA}^2}{c^2-1}$$

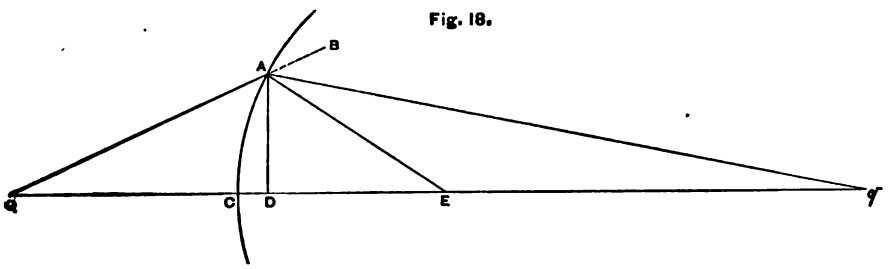
$$\therefore \left\{qE - \frac{ED}{c^2-1}\right\}^2 = \frac{\overline{ED}^2}{(c^2-1)^2} + \frac{(c^2-1)\overline{EA}^2}{(c^2-1)^2}.$$

$$\therefore qE = \frac{1}{c^2-1} \cdot \left\{ED \pm \sqrt{\overline{ED}^2 + (c^2-1)\overline{EA}^2}\right\}$$

From this formula the value of qE for any surface may be calculated. For lens of small aperture, the aberration is nal aberration then being only 1.07 times the thickness of the lens.*

No expedient has been discovered by which the spherical aberration of single lenses can be rendered less than 1.07 of their thickness; but if, instead of a double-convex lens, two plano-convex lenses be used, so placed that their convexities shall be turned towards each other, their combined aberration will be only 0.248, or about $\frac{1}{4}$ of their thickness, provided that the focal length of one be 2.3 times that of the other; and the spherical aberration may be wholly effaced by the combination of a double-convex lens C (Fig. 19) with a meniscus M, having suitable curvatures. In this case the convex side of M must be turned towards the object.†

Fig. 18.



in proportion to the square of the angular aperture of the lens; but for lenses of larger aperture, the aberration increases more rapidly.*

If n equals the index of refraction, r the radius of the anterior surface, and R that of the posterior surface of a lens, then, for parallel rays, the form for least aberration is expressed by the equation,

$$-\frac{r}{R} = \frac{4+n-2n^2}{2n^2+n}.$$ If $n=1.5$, the form for least aberration is a lens whose surfaces have their radii in the proportion of 1 to 6, with the side of deeper curvature towards the object—the longitudi-

Although it is hardly possible, in practice, to efface altogether the effects of spherical aberration, they have been so considerably diminished by the adaptation of the curvatures of lenticular surfaces, that in well-constructed telescopes they may be regarded as entirely removed

*If the length of the principal focus be taken as unity, the longitudinal aberration FG (Fig. 17) for lenses of different angular aperture will be as follows:

For 15° the aberration will be	0.095.
" 23° " "	0.062.
" 30° " "	0.150.
" 45° " "	0.375.

*Supposing the lens of least spherical aberration to have its aberration equal to 1, that of the other lenses will be as follows:

Best form	1.000.
Double convex or concave, with equal curvature	1.567.
Plano-convex, with convex side towards object	1.061.
Plano-convex with plane side towards object	4.206.
Plano-concave same as plano-convex.	

†C.

	1st Combination.	2nd Combination.
Focal length	10.000	10.000
Rad. of outer surface	5.833	5.833
" " inner "	35.000	35.000
M.		
Focal length	17.829	5.497
Rad. of outer surface	3.688	2.054
" " inner "	6.291	8.128
Focal length of combinations	6.407	3.474

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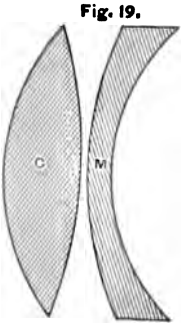
for all practical purposes. The work has been accomplished by giving to the two sides of the lenses different curvatures, so adapted that the aberration produced by

Fig. 19.



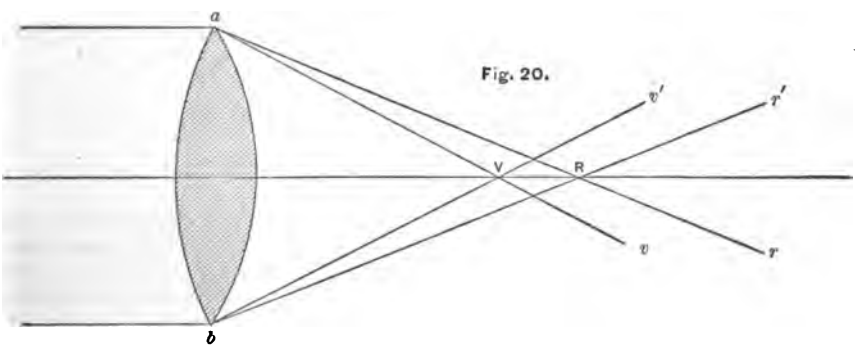
one shall be more or less counteracted by the aberration produced by the other.

(2.) *Chromatic aberration.* — White light, when refracted by a lens of any single transparent substance, like glass, is acted upon as by a prism, and dispersed into all the colors of the solar spectrum. This effect is shown in (Fig. 20), where V is the focus of the violet rays, which are most refracted, and R is the focus of the red rays, which are least refracted. A violet image is formed at V, and a red image at R, and the space VR is occupied by images of intermediate colors. An image of a point formed at V is violet, but surrounded by fringes of all the colors of the spectrum, the outer border being red.

To refract light, and still keep the colors united, it is necessary, after the rays are refracted, and thus separated, to use a substance of greater dispersive power, which brings the rays together again by refracting them only a part of the distance back to their original direction.

The problem is: can we make two lenses of different kinds of glass, with equal dispersive, but unequal refractive, powers? The researches of Euler and Dolland answer in the affirmative, by showing that the dispersive power of dense flint glass is about double that of crown glass, while the refractive power is nearly the same. Hence, a double-convex lens of crown glass AA (Fig. 21) is united with a plano-convex lens of flint glass BB, having a focus about double that of AA. BB corrects the chromatic aberration of AA, leaving about $\frac{1}{2}$ of the refractive power of AA as the effective refracting power of the compound lens. No exact rule respecting the ratio of the curvature can be given, because the refractive powers of different specimens of glass differ, and the proper ratio in each case is found by trial. Having found it, the two lenses have equal aberrations, but in opposite directions, while AA refracting more powerfully than BB, the rays are brought to a focus at a distance a little more than double the focal distance of AA.

Fig. 20.



Having explained the general princi-

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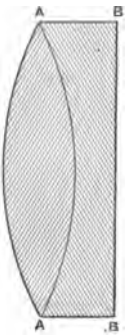
ples upon which achromatic lenses are produced, it will be satisfactory in a question of such importance to supply the mathematical details of its solution.

Fig. 21.



The problem is: to find what form must be given to two lenses of different refractive powers, to render the focal length of the compound lens, for light of any one refrangibility, equal to that for light of any other refrangibility. Let F′ and F″ be the focal lengths of the two lenses for light, of which the indices of refraction are n' and n'' for the media composing the lenses respectfully. Let f' and f'' be the focal lengths for light of which the indices of refraction are m' and m''. Let F be the focal length of the compound lens. The converging power of the compound lens, on each kind of light, is equal to the sum of the converging powers of the two lenses, separately, on the same kind of light. The *converging power* of the compound lens, therefore, on the light whose indices of refraction are n' and n'', is $\frac{1}{F}+\frac{1}{F''}$, and its converging power on the light whose indices of refraction are m' and m'', is $\frac{1}{f'}+\frac{1}{f''}$. But since these two converging powers must be rendered equal, we have, $\frac{1}{F'}+\frac{1}{F''}=\frac{1}{f'}+\frac{1}{f''}$. We have, then, to assign such magnitudes to the radii of the surfaces of the lenses as will fulfill this condition. Let R_1 and R_2 be the radii of the surfaces of the first, and r_1 and r_2 those of the surfaces of the second lens. When F equals the focus of parallel rays, r and r', the radii of the surfaces, and n the index of refraction of any lens, we have, by a formula of optics:

$$F=\frac{rr'}{(n-1)(r-r')}.$$

By this formula:

$$\frac{1}{F'}=\frac{(n'-1)(R_1-R_2)}{R_1R_2},\ \frac{1}{F''}=\frac{(rc''-1)(r_1-r_2)}{r_1r_2};$$

$$\frac{1}{f'}=\frac{(m-1)(R_1-R_2)}{R_1R_2},\ \frac{1}{f''}=\frac{(m''-1)(r_1-r_2)}{r_1r_2}.$$

But since

$$\frac{1}{F'}+\frac{1}{F''}=\frac{1}{f'}+\frac{1}{f''},$$

we have,

$$\frac{1}{F'}-\frac{1}{f'}=\frac{1}{f''}-\frac{1}{F''}.$$

Therefore,

$$\frac{n'-m')(R_1-R_2)}{R_1R_2}=-\frac{(n''-m'')(r_1-r_2)}{r_1r_2},$$

and consequently,

$$\frac{n'-m'}{n''-m''}=-\frac{(r_1-r_2)R_1R_2}{(R_1-R_2)r_1r_2}.$$

(n') and $(n''-m'')$ are the difference between the indices of the two lights having different refrangibilities, or the *dispersive powers* of the media composing the lenses for each of the two lights. If, then, the radii of the two lenses be so selected as to render $\frac{(r_1-r_2)-R_1R_2}{(R_1-R_2)r_1r_2}$ equal to the ratio of the dispersive powers of the materials of the two lenses for the two kinds of light, the latter are brought to the same focus by the compound lens.

Suppose the first a double-convex lens L (Fig. 22), with equal radii, and the second a double-concave lens L′, the surface of which, in contact with the first, has the same curvature with it, and, consequently, the same radius. Observing that when the convexities are turned in contrary directions, the radii have contrary signs $\frac{n'-m'}{n''-m''}=-\frac{(r_1-r_2)R_1R_2}{(R_1-R_2)r_1r_2}$ is now reduced to $\frac{n'-m'}{n''-m''}=\frac{r_2-R_2}{2r_2}$

Let us suppose that the double-convex lens is composed of crown glass, for which $n'=1.546566$, and $m'=1.525832$; and the double-concave of flint glass,

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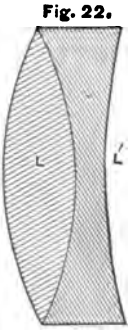
for which $n''=1.671062$ and $m''=1.627749$. We then have $\frac{n'-m'}{n''-m''}=\frac{.020734}{.043313}=\frac{r_2-R_1}{2r_2}$. Hence $r_2=23.47\times R_1$. The radius of the second surface of L′

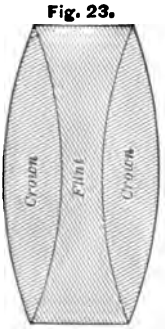
Fig. 22.



must in this case, therefore, be 23.47 times the radius of L.

Some of the earlier achromatic objectives were made of three lenses, as in (Fig. 23), a double concave lens of flint glass being fitted between two double convex lenses of crown glass. In June,

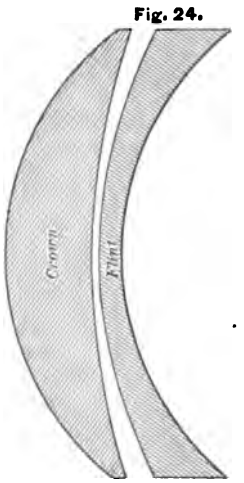
Fig. 23.



1860, Professor Steinheil communicated to the Royal Academy of Sciences at Munich, a notice of an object-glass of the form shown in (Fig. 24), executed according to the system of curves proposed by Gauss. The curves in this combination bear a considerable resemblance to the systems designed with express reference to the correction of spherical aberration, and for a long time object-glasses of this form were claimed by the most competent judges to exhibit a more complete achromatism, and in other respects more perfect definition, than was found with object-glasses of other forms.*

The problem presented to the mathematician, as to what shall be the form and disposition of the surfaces of two or more lenses composed of materials of different dispersive powers, which shall most effectually destroy the aberration of color and figure, is an indeterminate one; so that, for every lens of crown glass of positive focus, whatever the radii of its surfaces may be, a lens of

Fig. 24.



flint glass can be constructed which will form, when united with it, an achromatic and aplanatic object-glass. This allows a great range in the choice of curves, and a variety of conditions have been proposed by different authorities for determining the selection. The theory of telescope objectives is at this time being discussed by many able mathematicians, among whom, in our own country, are Professors Newcomb and Harkness, of Washington, and Professor Chas. Hastings, of the Johns Hopkins University. In regard to the form of objectives, Messrs. Alvan Clark and Sons, of Cambridgeport, Mass., whose reputation as

* Paper published by G. P. Bond in 1863 on "The New Form of the Achromatic Object-Glass introduced by Steinheil." Also, "Proceedings of the American Academy of Arts and Sciences." Vol. vi.

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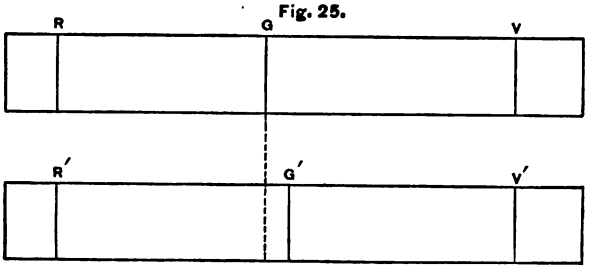
telescope makers is known throughout the world, in a letter to me, dated March 10, 1879, say: "Many forms may be used, but from our experience we have found that to *make the crown glass lens of equal curvature, and the flint glass lens nearly flat on the side next the eye*, is the most convenient, and *gives as good results as any other form;* of course, the curves must differ with different glass used; but the difference will be small." This is the form shown in (Fig. 21). If the dispersive power of the flint were just double that of the crown, the outer face of the former would have to be a plane surface to produce achromatism, but this is not generally the case. As no two specimens of glass made at different meltings have exactly the same refractive and dispersive powers, the optician must find the ratio of the dispersion of the two glasses, and then give the outer face of the flint such a degree of curvature as to neutralize the dispersion of the crown. Usually, this face will have to be slightly concave.

(3.) *Secondary Spectrum.*—The image formed at the focus of a so-called achromatic lens is not absolutely colorless. A difficulty arises from the fact that flint glass, as compared with crown, disperses the violet end of the spectrum more than the red end. If R, G, and V, (Fig. 25), are the centers of the red, green and violet in the spectrum given by a prism of the glass of which one lens is made, and R′, G′, and V′, are those of the other; and if the lenses are placed so as to counteract each other, and are of such curves that the red and violet are combined, the green remains slightly outstanding. If the second prism disperses the violet as much as the first one does, when they are reversed they exactly compensate red and violet. But the second acts more strongly than the first on the green, which is overcompensated; and if we weaken the second prism, so that the green and red are corrected, then the violet will be slightly outstanding. The defect is hardly noticeable in small telescopes, but in the immense refractors of two feet aperture, or upwards, this secondary aberration constitutes the most serious optical defect—a defect which, arising from the properties of glass itself, no art can dim-

Fig. 25.



inish. It has been suggested that this difficulty may be lessened by increasing the length of the instrument. But in doing this with glasses of such large size, engineering difficulties will be encountered which soon become insurmountable, and it is the opinion of many opticians and astronomers that "the limit of optical power for such instruments *has been very nearly attained.*"

In boring for water in the Wimmera district, Victoria, recently, a tree was passed through for 6 feet, at a depth of 250 feet, and the cup brought up several fruit stones similar to the nuts of plums; some were smashed, but the kernels were recognizable. It seemed evident that there was a grove of trees there.

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THE CYCLICAL USE OF STEAM.

From "The Engineer."

By the cyclical use of steam, we mean to imply the use of a given weight of steam over and over again in a cycle. In the development of motive power air may be thus used. A given weight may be heated, expanded, made to drive a piston in expanding, withdrawn from the cylinder, cooled down, and reheated and expanded, over and over again. In some forms of hot-air engine the initial air in the apparatus might be used for ever without addition of any kind, were it not for imperfections in the apparatus which permit the air to leak away. Can steam be thus employed? That it can take the place of air, and that a hot-steam engine might be constructed as well as a hot-air engine, no one doubts; but whether it can or cannot be used over and over again in quite another way, is a question of very great importance, and to the consideration of this question we wish to direct the attention of our readers. What we are about to say may correct some misconceptions, and prove specially useful to many of our younger readers.

In the steam engine as usually made there is an inherent defect which is prejudicial to economy. This defect is that before steam can be used it must be made, and that after it is used it is thrown away. Under this system the greatest amount of work which it is possible in theory to get out of one pound of steam expanded, say eight times, in a cylinder with 7 per cent. clearance at each end of the stroke, the absolute initial pressure being 100 lbs. on the square inch, is 159,433 foot-pounds, and the heat converted into work will amount to 206.5 units, or 20.7 per cent. of all the heat communicated to the water in the boiler, assuming that the feed-water is introduced at 212 deg. Thus 79.3 per cent. of the fuel consumed is wasted even in theory, to say nothing of practical losses by cylinder condensation, radiation, and so on. As we have shown, this loss is a result of the system of working which involves first the manu-eam, and secondly the destruction of this steam in a condenser or its waste in the atmosphere. To make this proposition quite clear, we will assume that one pound of water at 212 deg. is introduced into a boiler. It will then be converted into steam having a pressure of 100 lbs. During the process of conversion 1001 units—omitting fractions—of heat will be taken up or absorbed by the water. The resulting pound of steam, occupying a space of 4.33 cubic feet, being admitted to a cylinder and worked in the ordinary way—and by assumption without loss by external cooling—will part with 206.5 units of heat which will be converted into work. The remaining 794.5 units will pass into the condenser, or will escape into the air, as the case may be. If it were possible to rescue even a fourth part of this 794.5 units, and convert them into useful work, it is evident that the economy of the steam engine would be enormously augmented.

It will be seen that the loss of 794.5 units, out of a total of 1001 units, is entirely due to the throwing away of the steam which has been used, and the consequent necessity for obtaining a fresh supply from the boiler. Any attempt to prevent the loss in question must therefore be directed to devising means for using the same steam over and over again in a cycle. In order to do this we must work—with 100 lbs. steam—our engine between 328 deg. as the maximum limit, and 212 deg. as the minimum limit of temperature; that is to say, the engine must receive steam at 328 deg., the temperature corresponding to 100 lbs. pressure, and reject it at 212 deg., the temperature corresponding to a pressure of 14.7 lbs. It is not necessary that the fall in temperature should be brought about wholly in the cylinder. To do this would involve $\frac{100}{14.7} = 6.8$-fold expansion; but for the attainment of the best result this ought to be the ratio of expansion. If it is less, then the steam would have to be reduced in pressure and temperature by external

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cooling, or expansion without doing work, and either plan would represent a loss of useful effect. An engine constructed on this system would have no more to do with the external atmosphere than an ordinary condensing engine has. Its back pressure, however, would be just the same as in the case of a non-condensing engine, only in lieu of an atmosphere of air, the exhaust steam would always be discharged into an atmosphere of steam, contained in a vessel which would be in periodical free communication with the exhaust port. The efficiency of a pound of steam worked in such an engine would be identical in amount with the efficiency of a pound of steam worked in an ordinary non-condensing engine, and would be considerably less than equivalent to 150,433 foot-pounds; but we could afford to disregard this loss of efficiency which would—as will be seen presently—be made up many fold by the novel conditions of working, provided it were possible to use the same steam over and over again.

The cylinder of our imaginary engine has received 1 lb. of steam, but it will reject a pound of steam and water mixed, because a portion of the steam will be condensed in the performance of work. As much will be condensed as would be converted into steam of 100 lbs. pressure from water at 212 deg. by the 206.5 units of heat converted into water. As 1001 units are needed to thus convert 1 lb. of water, a very simple calculation will show that 206.5 units will convert .206 lbs. of water nearly; consequently there will be discharged from the cylinder .206 lbs. of water, and .794 lbs. of steam at 212 deg. The water will occupy a space of, omitting small fractions, 6 cubic inches, and the steam a space of 20.93, or in round numbers 21 cubic feet.

Now, it will be seen that to restore this mixture to the condition of steam of 100 lbs. pressure on the square inch, nothing is needed apparently save to re-evaporate the 6 cubic inches of water, and to restore the sensible heat lost by the steam. But 6 cubic inches of water will fill a space of $6 \times 270 = 1620$ cubic inches of steam at 100 lbs. only, or 5.43 cubic feet at 212 deg. This would not suffice to bring up the pressure to anything like that which it was when steam was first admitted to the cylinder. It is evident, therefore, that something more must be done than merely to re-evaporate the water which was condensed in the performance of work. Three courses are open: We may compress the steam until it occupies a space of 3.438 cubic feet, or we may apply heat to it until it assumes the required pressure, its volume remaining constant, or we may do both. If the steam be compressed adiabatically, all the work expended in compressing it will be returned during expansion. When compressed, communication would be opened between the vessel containing the compressed steam and that obtained by re-evaporating the water of condensation. We would then at once have 1 lb. of steam at 100 lbs. on the square inch to be introduced into the cylinder and do its work there. The cycle would thus apparently be complete, and for each pound of water which would otherwise have to be evaporated we would have now to convert into steam only, in round numbers, one-fifth of a pound. This represents an enormous saving.

As a matter of fact, however, the cycle is not complete. It is true that the work expended in compressing the steam may be all given back again, but it must be given back again in the cylinder, in lieu of work which would otherwise be available for driving machinery. To put this in a practical point of view, our imaginary steam engine must have a large compressing pump tacked on to it, and this pump would use up so much power that no economy would be realized.

As regards the second scheme nothing whatever is to be hoped from it, the temperature which the steam must acquire to even triple its pressure being far too great for adoption in practice.

Hitherto we have regarded steam as though it was a gas, and entirely distinct from the water of condensation. In practice, however, the steam would be delivered from the engine as a cloud; it would be saturated with moisture. It is evident that if by any device its volume could be largely augmented, even without increasing its pressure, by a moderate application of heat, that it could be used over again, not, indeed, in the first, but in a second or condensing cylinder. Now a dry gas expands by the application of heat at the rate of one-nth of

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the volume per degree of temperature. The value of n being $461 + t$ where t is the sensible temperature; thus the senisible temperature of air being 212, then $461+212=673=n$ and expansion would take place at the rate of an increase of $\frac{1}{673}d$ of the volume for each degree. But wet steam constitutes a remarkable exception to the rule; n is not a constant but a variant, and the rate of expansion is three or four times that of dry steam under certain conditions. If then heat be applied to the steam as it escapes from the first cylinder, it may be assumed that a very considerable economy may be gained. We are not aware of this plan having been fully tried. Mr. Cowper devised many years since what was known as the "Cowper's Hot Pot," namely a receiver between the high and low pressure cylinder of a compound engine, in which, by the aid of a jacket and live steam from the boiler, it was intended to raise the temperature of the steam and dry it before it entered the low-pressure cylinder. The plan was tried, but it did not succeed in effecting any saving of fuel. But it would be wrong to condemn the system as a consequence, because the failure probably resulted from the fact that the steam was not really heated or dried in the hot pot; indeed, a rise of 1 deg. or 2 deg. was the greatest attained. There is much reason to believe, nowithstanding the failure of Mr. Cowper's scheme, that if the exhaust from the high-pressure cylinder of a compound engine was led through the tubes of a superheater of adequate size before it was admitted to the low pressure cylinder, that great economy would result; but it must not be forgotten that this arrangement would after all not provide for the use of the same steam over and over again. In other words, the steam, no matter how it was superheated or how many cylinders it traversed, must at last be thrown away; and it must be thrown away because it becomes, to use a word applied in a somewhat similar sense by Sir William Thompson, degraded. It loses both pressure and temperature, and this pressure and temperature cannot be restored by the re-evaporation of the water condensed during the performance of work.

It is, however, possible to use the same steam over and over again, but under conditions different from those which we have indicated. A pound of gaseous steam may be treated like a pound of air, and made to work as in an air engine. But the advantage, if any, possessed by steam over air is neutralized by the inconvenient circumstance that superheated steam exerts a solvent influence on cast iron, and cuts away cylinders and valve faces very fast.

It is not to be supposed that this is the first time that the use of steam many times over has been suggested. On the contrary, as we have shown, the economy to be effected by any scheme which would enable the idea to be carried into practice, even in an imperfect way, is so so great that many inventors have tried what they could do with the principle. The most recent effort in this direction is that of Mons. Testud de Beauregard, of the Rue Lafayette, Paris, whose invention possesses the charm of novelty at all events, to a considerable degree. The principle on which he proposes to work is very simple. The exhaust steam from an engine is reduced to a temperature of 212 deg. by passing it through a tube coiled in a vessel of water of somewhat less temperature. This steam is then returned into a chamber or regenerator through a pipe in which is a species of induction jet of high pressure superheated steam from a small boiler. The steam pipe to the engine opens into the regenerator, and a second jet drives the steam from the regenerator into the engine. That a jet possesses sufficient power to do this we know from experiments on the use of mixed air and steam, which we have ourselves carried out. But all the obstacles which we have named in the course of this article to the use of steam twice over appear to apply to this device. M. de Beauregard, however, pins his faith on the result of an experiment, which he thus describes: "Wrapped up in a wet cloth kept moist by boiling water, a glass mattrass with a long vertical neck was kept filled with saturated steam at 100 deg. Cent. This flask was connected to a superheating apparatus, so as to receive therefrom, through a special cock superheated and desaturated steam at 500 deg. to 600 deg. Cent. On opening the cock the flask was invariably shattered to pieces, owing to the instantaneous expansion to

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which the steam it contained was subjected, and this happened although the large opening in the neck seemed sufficient for the sudden expansion of the steam." M. Beauregard considers that he has here made a new discovery: "The regeneration of negative steam, the instantaneous transformation of heat into expansive power." We need hardly tell our readers that M. Beauregard is mistaken, and that he is no nearer using steam twice over than any one else. The mixture of highly superheated with moist steam was long since proposed by Wethered, and the system has been largely used, and with good results, but with nothing like those anticipated by M. Beauregard. We mention his invention, indeed, as a warning to others. But we cannot help adding at the same time that so much uncertainity exists concerning the behaviour of fluids in such a condition of unstable equilibrium as is steam cooled down from a higher temperature to 212 deg. and saturated with moisture, that it is highly desirable that a very simple set of experiments should be carried out, to ascertain the pressures attained by condensing given weights of very highly superheated steam into given volumes of saturated steam. It is not impossible that higher pressures could be reached than theory points out as probable. We have already said that the expansion of steam at or near the boiling point is very irregular, and it is apparently irregular for equal increments of heats. There is here a possible source of economy not yet fully examined, but the broad fact remains that steam cannot be used over and over again through cyclical changes. At least the genius has not yet come amongst us who can show how it is to be done.

THE PROTECTION OF WOOD AND IRON BY PARAFFINE.

From "The Builder."

Dr. Eugen Schal gives some interesting information on this subject in the *Wurtembergische Gewerbeblatt.*

In chemical technology great difficulties sometimes arise when it is desired to manufacture, on a large scale, preparations which may be obtained with ease in the laboratory. In most cases the reason of this failure is the fact, that in the manufacture the use of glass, porcelain, platinum, &c., which successfully resist the effects of the various chemical agents must be dispensed with, and cheaper and less easily breakable materials, such as iron, copper, lead, and wood, substituted. Wood especially cannot be replaced by any other material in the wholesale preparation of muriatic lyes, although the same, according to the strength and temperature of the liquid, undergoes sometimes very rapid destruction.

Dr. Schal says he acquired this experience more particularly in 1874-77, in alizarine manufactories, and that he found in paraffine a means which efficiently protects the wood against damp, acids, and alkalis, and by which a great saving is effected. The wooden vessels used, especially tanks of pine wood, for boiling acid and alkaline lyes, as well as casks of oak of the heaviest weights, for separating acid alizarine lyes at a pressure of a half to two atmospheres, were generally totally rotton after a few months, but they lasted for two years when impregnated with paraffine.

Before treating with paraffine, however, the vessels must be thoroughly dried for about three weeks by leaving them in warm and dry air, in order to prepare the wood for the absorption of the paraffine solution in its pores. The latter solution is prepared in the following manner: A part of the paraffine is melted in a spacious metal vessel over a moderate fire, the mass being stirred, the boiler taken from the fire, best moved into the open air, stirred until the mass begins to congeal at the edge, and then about six parts of petroleum, ether, or sulphuret of carbon are poured in, and stirred until solution. The preparation is then put into vessels that may be hermetically closed, or it may be used at once. In preparing the paraffine solution great care must be exercised, as

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paraffine, as well as petroleum, ether, or sulphuret of carbon especially, are very inflammable, and as even the vapor of the two last-mentioned substances, if mixed with air, may give rise to dangerous explosions. Those substances must, therefore, be kept in a cool space, far from light or fire, and well stoppered.

The wood is best saturated in dry and warm weather, as then it dries more quickly, and a smaller quantity of the solving agent is necessary. In winter six parts of the solvent generally do not suffice. This proportion changes with the quality of the paraffine and the temperature; paraffine solving with difficulty is better than the more readily soluble article. Vessels easy of access, such as tanks, tubs, &c., are coated in the open air with the solution as long as the wood will absorb it. The solvents evaporate very quickly, leaving the paraffine behind, so that two or three coatings may be laid on in succession. If the vessel is to be exceptionally well prepared, it is left for a day to dry, and then another layer of the paraffine given.

For vessels in which steam is used for boiling the liquids they contain, he applies after a few days a coating of oil varnish, because the melting point of paraffine is below the boiling point of water, and it is thus in time driven out of the pores by the water.

Instead of oil varnish, the vessels, after being well rubbed down, may also be coated with a thin solution of soluble glass, then dried and washed with diluted hydrochloric acid. The silicic acid thus formed clogs up the pores from the outside, and provides a protection to the paraffine against the hot water. For vessels which are used only with a moderate heat or cold, the coating of paraffine suffices perfectly. The paraffine is hardly dissolved by diluted cold alcohol, is not poisonous, and may also probably be used with advantage for vessels for keeping liquid. In the case of barrels, the solution was poured in simply after drying them; for an oak barrel holding nine to ten hectoliters, 1 kilo of paraffine dissolved in petroleum ether was required. All openings were then well closed and the barrel rolled about and over for about an hour, so as to bring all parts in contact with the solution. The barrels were finally left standing on their ends for half a day, after which time the remainder not absorbed was emptied, and used for the outside coating. Before applying the solution outside, however, the barrels must be well cleaned, for dirt naturally closes the pores of the wood. As these barrels were very expensive, and had to sustain a pressure of two atmospheres, besides being exposed to a high temperature, they received on both sides an additional coating of oil varnish. It is, however, necessary to let such a barrel stand in the open air at least a fortnight for drying, and, as a precaution, fire must be kept away from the barrel while being prepared. As a further precaution, in applying the solution inside, the workman must not be left alone, as it frequently happens that stupefying vapors from the solvent of the paraffine arise, which stupefaction, however, soon disappears in the open air. The oil varnish may also be diluted with petroleum ether, poured into the barrel, and then the latter rolled about, as above described; but many places escape saturation in this operation. After coating with varnish, the barrel is once more dried, and then filled with water, in order to force out the combustible gases. This is much to be advised, as an explosion once took place in consequence of a workman trying to enlarge a hole with a red hot iron, contrary to orders. After the last operation, the inner sides of the various vessels are rubbed down with a dry duster, so as to take off all loose particles.

If impregnation of wood is intended on a large scale, the wood is best stacked in iron boxes, the paraffine solution poured over it, the solution not absorbed drawn off after some time, the solvent forced out of the wood by means of warm air, and recovered by condensation in a cooling apparatus.

If the various manipulations are carefully carried out, the duration of vessels thus prepared is increased from four to six fold, while the outlay is comparatively small, leaving out of consideration that the contents of such vessels are frequently lost by the bottom being forced out.

Paraffine, melted with equal parts of linseed oil or rapeseed oil, is also useful for coating iron vessels, which, without a

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substantial preservative, are very liable to rust in manufactories of chemicals.

Paraffine likewise protects skin efficiently against wet, alkalis (especially lime), acids, &c.

Dr. Schal says he often found that workmen in alizarine factories suffered much from sore, ulcerating and swollen hands, especially during winter. After the workmen began to use (twice daily) a solution of paraffine with rapeseed oil and petroleum, chapped hands became a scarcity.

The solution is produced by melting three parts each of paraffine and rapeseed oil, removing it from the fire, and adding eight parts of petroleum while stirring the mixture. Before using, the solution is stirred a little, and the hands rubbed with it while they are clean and dry. In larger factories, earthenware and tin vessels, filled with this ointment, are placed at convenient spots, and it is believed that the manufacturer, as well as the workman, will find this pay.

ON THE STRENGTH OF IRON AT HIGH TEMPERATURES.

By J. KOLLMANN.

From "Abstracts" of the Institution of Civil Engineers.

In this memoir the author gives the results of a series of investigations carried out in 1877–78 at the Oberhausen works upon the tension and resistance to compression of wrought iron and steel at high temperatures, which, together with other experiments, were undertaken to obtain a basis for a theory of the action of the rolling mill and of the construction of rolls. The materials investigated were of three kinds, namely, fibrous malleable iron, fine-grained iron, and mild Bessemer steel, the samples used being of the average ordinary qualities produced in the works. Two testing machines were used: in one the strain was applied by hydraulic pressure, and in the other by weights applied directly. The elastic limit was determined by a contrivance called a multiplier, consisting of a pair of unequal armed levers with set screws on the shorter arms, whereby they are attached to the test piece. These remain closed while there is no permanent elongation, but when the limit of elasticity is reached the arms separate, the divergence being read off on a divided scale attached to the longer sides.

The experiments were made with test pieces of two different sizes; those for the smaller hydraulic machine were either round, of 13 millimeters (0.51 inch) diameter, or square of the same dimensions on the side. Those for the larger one measured 40×10 millimeters (1.575×0.394 inch). They were brought up to the required temperature by heating either in a coke fire or a portable forge; two exactly similar pieces being used, one for the experiment and the other for the determination of the temperature, which was done by means of a water calorimeter of a somewhat special construction. The final temperature of the broken test piece was sometimes determined in the same way, but generally the loss of heat was computed by observing the time and applying the results of a table specially computed from masses of iron allowed to cool in the air for definite periods.

The experiments were made at temperatures varying from 20° to 1,080° Centigrade, and the progressive diminution in strength is expressed in terms of that at 0°, the latter being made = 100:

Centigrade.	Fibrous Iron.	Fine-Grained Iron.	Bessemer Iron.
0	100	100	100
100	100	100	100
200	95	100	100
300	90	97	94
500	38	44	34
700	16	23	18
900	6	12	9
1,000	4	7	7

—(*Verhandlungen des Vereins zur Beforderung des Gewerbfleisses.*)

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THE USE OF CEMENTS.*

From "The Building News."

THERE is probably no more deeply-rooted conviction prevalent among architects than the belief we cherish in the excellence of Roman mortar. The Romans distinguished themselves among all the conquering nations of antiquity as mighty builders, and throughout every country which they subdued we find the remains of public works and buildings, more or less perfect, as evidences of their occupation and monuments of the skill and enterprise of their architects. The builders of Rome undoubtedly made use of the limestones of the countries in which they worked, and sometimes they came across good limes of a cementitious character, and at others they found only fat or rich limes. In the former case we find the structures which have escaped destruction at the hands of man still extant; in the latter, where the mortar was made of bad or unsuitable lime, the buildings have crumbled away and have become obliterated by natural causes. The secret of the excellence of Roman mortar, so often and so laboriously sought after, is to a great extent a delusion, and we praise the mortar of the ancients only because all the bad mortar has long since perished. It is nevertheless a fact that we owe indirectly to the Romans the discovery of all our modern cements, for it was in consequence of researches made respecting the durability of ancient mortars that the reason for what has been termed the hydraulicity of limes was explained early in the present century. To our own countryman, Smeaton, the builder of the Eddystone Lighthouse, and to Vicat and others on the Continent, must be assigned their due share of credit for these discoveries; and their labors have since been ably supplemented by the investigation of Pasley, John, Fuchs, and Pettenkofer. I will not occupy your time with more than a brief record of the gradual growth of our knowledge concerning cements, and I propose only to glance at the history of these materials, which is one of much interest. I wish rather to treat of the employment of cements for practical purposes, and to invite your attention to a brief consideration of the manner in which we have availed ourselves of the knowledge which we have acquired concerning cements and cement action. I must first dwell for a few moments, however, upon the use of mortar in London in times past, because my argument will involve a clear appreciation of this part of the subject. After the great fire in 1666, London, as we all know, sprang up, by royal enactment, as a brick city, and the quaint wooden buildings which had been the characteristics of the London of the past, were no longer recognized by the new Building Act, and were condemned, as they still are, by the district surveyors. There must at once have been a great demand for lime, and the quarries adjacent to the metropolis were placed, no doubt, under heavy contributions for the necessary materials. The chalk nearest to London, on the banks of the estuary of the Thames, and north and south—at Watford and Croydon—is the white, flint-bearing, or, as geologists term it, "the upper chalk"—one which yields a fat, pure lime, having little or no cementitious properties, and furnishing, therefore, a mortar of the worst possible kind. Further away—on the banks of the Medway, and on the chalk ranges of Dorking and Guildford, or northwards, in various parts of Buckinghamshire—we find the grey chalk a totally different substance, and one capable of yielding a lime of good quality. But it is impossible to examine the mortar of two hundred years ago without being convinced that it was white lime that our ancestors prized, and mixed with the smallest possible quantity of sand. The mortar of those days speedily dried, or obtained a false set, owing to the absorption of the water by the porous bricks, but it never became truly indurated, and, after all these years, it is found in the joints of many an old house in the city as a mere crumbling cake, which can be crushed into dust between the finger and thumb,

* A paper read before the Architectural Association, by Mr. Gilbert R. Redgrave.

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and has no cohesive strength whatever. Just listen to what General Treusart says concerning this kind of lime: "Thus chalk-lime mortar, when wet, is a pulp or paste, and when dry it is little better than dust." No wonder at the clouds of fine powder which half-blind us when any work of demolition is in progress in the older parts of London; the only strange thing is that the brickwork holds together so long as it does.

It seems somewhat astonishing in these days of rapid building to read the specifications of even one hundred years ago only, and to learn the amount of labor then bestowed upon the preparation of even such mortar as this. Let me read you a passage from the "Builder's Price-book" of Batty Langley for the year of grace 1748. Speaking of what he terms "terrice mortar," probably trass, as he says terrice is a kind of sand brought from Holland, he tells us "the best terrice mortar is made with two bushels, &c., of hot lime, and one bushel, &c., of terrice, well incorporated by beating, and which quantity to beat well is a good day's work for a laborer." Think of this, poor overworked larryman, three bushels of mortar per diem "a good day's work!"

It was, I think, out of no disrespect for the white chalk lime, but rather from some strange belief in the color of the grey lime, that about the middle of the last century a fondness arose in London for what was called stone lime, such as that of Dorking or Merstham—that is a lime of stone color—for I can see no other reason for calling this chalk lime a stone lime, which it certainly is not. It was a fallacy dating back to the time of Vitruvous, that the harder or denser the stone from which the lime was burned, the harder the mortar made from it would eventually become. Smeaton was, perhaps, the first engineer to demonstrate this to be a mistake. So strongly was the truth of this fact believed in, however, that some have thought that an opportunity was taken of this error, to introduce the Surrey and Medway limes, under false plumes, by terming them stone-limes, to convey the impression that they had been burned from limestone rock; indeed, Smeaton tells us such was the case. My own opinion is that certain grey limes had gained the reputation of being strong limes, that is, capable of uniting large volumes of sand, and that it was the color which gave the name, in this instance, of stone lime.

Pasley says, respecting this commonly-received opinion of the strength of grey lime: "We found by repeated experiments at Chatham that one cubic foot of Halling lime (very similar to that of Dorking) weighed nearly the same when fresh from the kiln; and by the gradual addition of water, that it dilated to the same increased bulk in the state of quicklime powder; but, when worked up into mortar not too short for use, that it would not bear quite so large a proportion of sand as the common chalk lime had done; this experiment leading to a result in opposition to the common opinion amongst the builders in the metropolis, which is that the Dorking and Halling limes, as being stronger (limes), will, when made into mortar, bear more sand than common chalk lime."

We may assume that this rise of the grey lime in public favor was partly due also to the increased facilities of carriage, by means of which the better limes were able to compete with the fat limes, which had been hitherto more readily obtained around London. Whatever may have been the reason for this preference, practical builders, doubtless, soon found that the grey chalk lime yielded a far better mortar and would set harder with more sand than that made from the white chalk and pure lime; but "Dorking stone lime" continues to this day a favorite piece of specification idiom.

The natural cement stones of the neighborhood of London were discovered by Dr. Parker, and specified for cement-making by Messrs. Wyatt & Parker, in 1796. They patented the mode of making what was called Roman cement, by means of calcining the septaria or masses of nodular limestone found in the London clay. In course of time it became known that very similar results could be obtained by combining mixtures of clay and lime or chalk mechanically, and artificial cements, such as those of Vicat and Pasley, became largely employed. This manufacture paved the way for Aspdin, with his Portland cement, patented in 1824, but it was not until 1847, or thereabouts, that the manufacture of Portland cement was perfected, and that what we

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now regard as Portland cement was made use of upon any scale.

I have said thus much on the history, in order that I may prepare the way for my inquiry into our mode of using these cements, and glance at the extent to which they have supplanted lime. This may enable us perhaps to ascertain the causes of our failure, and properly to appreciate the advantages we should gain from the more extended use of cements.

I am going to maintain that in good Portland cement we possess the best building material of the day, infinitely better than half the rubbish we make our houses of or pave our streets with, and a hundred-fold better when used as mortar than the compound we still go on specifying, as if we knew no more than our grandfathers of the properties of limes and cement. I trust I am not heretical in these matters, but I am so firmly convinced that lime, as now employed, will shortly become obsolete, or nearly so, as a building material, that I am able to speak out boldly in favor of cements. This brings me to my subject —the use, or, rather, the uses, of cements; for we are almost daily adding to our store of knowledge concerning the numerous constructive purposes for which cements may be made available.

Before going further, I wish to be clearly understood in respect to the meaning of the term "cement." By the word "cement," as it is now used in building, a substance is implied which, when treated with water, will set or indurate without change of form. Limes of every variety show more or less energy to change their physical condition, when water is poured over them. Pure limes, such as those made from Carrara marble or white chalk, instantly unite with the water or become hydrated, expand to two or three times their bulk, develop intense heat, and fall to a powder. Very hydraulic limes, under the influence of water, show at first hardly any sign of action. They are termed by builders very "dead," and only after the lapse of hours, or even days, crumble into coarse gritty fragments. Such limes, if ground, or mechanically reduced to an impalpable powder, may solidify without heat or apparent expansion, and acquire a set of the same nature as Portland cement. These limes are true natural cements. Between the active pure limes and the natural cements are an infinity of hydraulic or partially hydraulic limes, some of which, namely, those of a dangerous type, will at first set under water, which is what the term "hydraulic" really implies, or in air, and gradually fall to pieces; while others, on the contrary, will at first crumble to a fine powder, which powder, however, on being worked up with more water, will set, after the manner of cement. Limes of this kind are termed by Vicat "intermediate limes," as they partake of the character both of limes and cements, and are intermediate in their action between the two. The eminently hydraulic limes of the lias formation, which are ground and sold as "lias cements," are natural cements of the former class; while all argillaceous limes, which will go abroad when treated with water, and subsequently set when made up with sand, belong to the latter class.

It may be useful here to point out that Portland cement (which is one of the very highest quality when properly made) sometimes, owing to defects in its manufacture, presents more the characteristics of an intermediate lime than those of a true cement. Thus it may, from imperfect calcination, faulty proportions, or undue admixture of the ingredients, blow and fall to pieces, after having become set, or it may crumble and fail to acquire cohesion when mixed with water; or, lastly, it may set so slowly as to be scarcely capable of being used for cementitious purposes at all. Portland cement, in fact, although the manufacture has now been brought to great perfection, is not wholly free from fluctuations in composition, which, in former times, brought great discredit upon the material, and which during the early days of its employment, caused it to suffer by contrast even with Roman cement.

The next consideration is the cause of cement action, that is, the explanation of the facts I have just been describing. Why do some limes swell up and fall to pieces when treated with water, while others remain wholly inert? The cause of hydraulicity was, to a certain extent, explained by Smeaton, who found by exposing the Aberthaw lime to the action

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of acid, that he obtained a residue of clay, and that all good "water-limes" examined by him left this sort of residue, while the pure limes, which were devoid of hydraulic properties, were entirely dissolved. He therefore rightly attributed this peculiar action to the presence of the clay. In his own words, he says: "In burning and falling down into a powder of a buff-colored tinge, and in containing a considerable quantity of clay, I have found all water limes to agree." Smeaton, who owned that he was no chemist, does not appear to have known the true reason for this action. It remained to Saussure to announce that this property depended solely upon the presence of the clay, while Descotils, in the year 1813, pointed out that the cause of the phenomenon was due to the presence of a large quantity of silicious matter, disseminated in very fine particles throughout the texture of the mineral. The chemistry of the action of cements and the formation of silicates in the kiln, which silicates become hydrated and rearrange themselves in consequence of the difference of their affinities, in the presence of the water, was first thoroughly explained by John, and the theory was perfected by Fuchs, of Munich. The study of this branch of the subject is one of great interest, and those who wish to pursue it further may do so by consulting the essay on lime in Knapp's "Technology."

It is strange that, although this action is in the main a chemical one, it can be greatly influenced by purely physical causes. To illustrate this, I will quote a recent and curious experiment of Dr. Knapp's in the laboratory at Brunswick. The avidity of quick lime for water is one of the strongest we know of, and the rapidity of the combination of the lime causes so much warmth to be evolved that the particles are immediately raised to a red heat. Conflagrations, we know, often occur from what is termed the slaking of lime. Now, if quick lime be reduced to powder in a pestle and mortar, and this powder be tightly rammed into a hollow cylinder perforated with minute holes, and fitted with screw caps to close the ends; on placing this lime-cylinder in water, the moisture can only reach the enclosed quicklime very gradually and in very small quantities; the result is, that instead of slaking to a powder, the lime becomes converted by its hydration into a very hard and solid mass, as different as can well be imagined from ordinary slaked lime. Here a well-known chemical action is changed by purely physical means. Some chemists have thought that in the case of mixtures of lime and silicates, that is, in those limes which are more or less hydraulic, the particles of quicklime, being coated over with an envelope of silicious matter, the water is only permitted to approach the lime very gradually, as was the case in the cylinder experiment I have described; and this theory has also been put forward by a German chemist to explain the reason for the peculiar action of General Scott's cement, or selenitic cement, as it is termed. I am afraid I am devoting more time than you will care for to these chemical questions, but I think they will enable us to appreciate better the action of cements. To sum up briefly the foregoing facts: Pure limes which, after falling into a powder, are made up into a paste and mixed with sand, yield mortars which have no inherent setting power, and can only become indurated by the slow and gradual recombination with carbonic acid. This re-formation of the carbonate can only proceed where atmospheric air, or water charged with carbonic acid gas, can penetrate, and the centers of thick walls, even after centuries, are often found with the mortar still in the state of putty, as when first used. Cements, on the contrary, owe but little to the atmosphere; indeed, true cements indurate better beneath the water than in the air. They possess in themselves the power of solidifying or becoming indurated, and attain their greatest strength in a few years at the most. It is a question which can scarcely be said to have been finally settled how long cements continue to harden; indeed, cements vary so much in this respect that the time differs in almost every sample, according to the composition and the degree of firing. Cements of the Roman type stand at one end of this scale, for many of them attain their full degree of hardness or tensile strength in from twenty to thirty days; while dense, well-made Portland cement of the highest quality would seem, from Mr. Grant's experiments, to continue to improve for seven years, and

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constitutes the other extreme of the scale.

In speaking of cements, I have purposely avoided all mention of that class of substances which, when added to rich or fat limes, impart to them hydraulic properties. These materials are puzzuolana, trass, arenes or volcanic sand, and many kinds of calcined argillaceous earth. There can be little doubt that all these substances owe their influence on mortars to the soluble silica contained in them. By soluble silica, I mean that variety of silicic acid which when treated with acids will gelatinize. Silica when heated to bright redness in the presence of bases acquires this soluble form, and most calcined clays, and volcanic minerals, which have been exposed to high temperatures, are more or less rich in gelatinous silica. Mortars compounded with pure lime and a sufficient quantity of substances capable of converting them into cements become, for the purpose of the arguments I am anxious to place before you, equivalent to cement mortars. Unfortunately, however, these mortars are rarely employed, except by engineers for docks, foundations, and other similar purposes, where the solvent action of water is dreaded. Occasionally, when, owing to the difficulty of obtaining good sand, the builder employs with fat limes, burnt ballast or broken bricks, which are artificial puzzuolona, a mortar which sets surprisingly hard is obtained. Such good mortars are, however, exceptional, and their excellence is due only to the action of the "aggregate," and not in any way to the quality of the lime.

I now return to my subject, and propose to place before you the arguments in favor of employing cements instead of limes for mortar-making. First, cements will unite much larger quantities of sand and building materials into a homogeneous mass than limes, and they are therefore more economical to use than limes. I am sure that the plea of economy is one of the very strongest arguments of the present day, and therefore, though this is not my best plea, I introduce it first. Rather than take the price-book values of lime, cement and sand, and with them construct an imaginary set of tables to show how the prices would work out, I will avail myself, on the present occasion, of the admirable series of experiments recorded by Mr. Colson in a paper presented to the Institution of Civil Engineers in 1878, in which this subject is most fully and ably dealt with. I am the more tempted to place before you Mr. Colson's figures, because he has, with the painstaking care and accuracy which mark all his observations, not only given us the cost of different mortars, but also the actual strength of each of the various mixtures. His experiments will be all the more interesting, I think too, because the paper containing them was not read and discussed at a meeting, but formed one of the selected papers, published in Vol. 54 of the Proceedings of the Institution of Civil Engineers. It has, therefore, hitherto, not attracted that share of attention from architects and engineers which the importance of the subject demands. I will convey to you Mr. Colson's observations as far as possible in his own words:

"The object of these experiments," he tells us, "was to ascertain what proportion of Portland cement and sand would produce a mortar equal in strength to, and as convenient to work as, grey lime mortar, mixed in the proportions ordinarily adopted for constructive purposes." I may here observe that the difficulty in the use of cement mortars with large quantities of sand is their want of plasticity, and it is necessary to contrive means to overcome this, or the workmen will not employ them, except in a very liquid, and therefore very objectionable, condition. This tendency to shortness can be obviated by introducing chalk, lime dust, loam, or other substances which produce a fat unctuous paste when treated with water, but all these materials tend to weaken the mortar. Still, it has been found, from careful experiments, that within certain limits it is possible to introduce even clay (which is, perhaps, the cheapest diluent which can be obtained) without reducing to any very serious extent the tensile strength of the mortar. The following series of experiments is very interesting, bearing as it does directly upon this point. The mortar was, we are told, in each case mixed to a workable consistency, equal, in fact, to the condition in which it could be used in the work. Mr. Colson's testing was carried out by by means of

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briquettes, similar to those used in ascertaining the strength of Portland cement, having a neck of $1\frac{1}{2}$ in. square, equal to a sectional area of $2\frac{1}{4}$ square inches. The mortars remained in the moulds until sufficiently hard to admit of removal. At the expiration of six months the blocks were tested for tensile strength, the results being shown in the first table. Mr. Colson says, respecting the samples of common lime mortar, that "the induration or chemical set had penetrated only to the extent of $\frac{1}{8}$ in. to $\frac{3}{16}$ in.; but, in a majority of instances, only $\frac{1}{8}$ in. The remainder of the area of the fracture had only dried, and could be crushed in the hand without any great exertion of force." The cement mortar with six, eight, and ten parts of sand, was, we are told, of "such a raw, harsh character, that it would be practically impossible to use it in a satisfactory manner. In order, therefore, to render it somewhat more convenient for working, a small quantity of lime or yellow loam was added, thus rendering the mortar more plastic and tenacious."

"The result of further experiments shows that the addition of lime and loam reduces the initial strength of cement mortar considerably, the reduction due to the addition of loam being more marked than by the addition of lime. The quantity of unslaked lime or loam, viz.: one-twelfth the bulk of the sand was found to be as small a proportion as could be used to give the necessary tenacity."

Mr. Colson tells us that the experiments made with these mortars in brick joints "were not altogether satisfactory, inasmuch as the appliances at hand were not sufficiently accurate and delicate to justify a ratio of comparison. It may, however, be stated that the general result went to prove that the adhesive power of mortar, mixed in the proportions of eight of sand to one of cement, with the addition of loam, was superior to grey lime mortar mixed in the proportion of two of sand to one of lime."

The second table shows the comparative cost of these different descriptions of mortar. As Mr. Colson points out, "such estimates must be received with caution, because difference of locality would exert a great influence upon the cost of production. The following statement is a close approximation of the cost of the several descriptions of mortar, the charge for labor and water, and also the bulk of mortar produced, being in each case the mean result of experiments."

The second argument in favor of using cement in lieu of lime is, that cement possesses an adherent chemical set, or power of induration, whereas fat limes can only become indurated either by the slow and gradual influence of the carbonic acid contained in the atmosphere, or in consequence of the materials mixed with it to make the mortar. I have already, in the earlier part of this paper, dealt with the setting power of cements and the re-carbonation of limes. But it may be as well to glance at the facts again, to see what they imply. Cement mortar has everything necessary in itself, in whatever position it may be placed, to become hard; all that it requires is a reasonable amount of moisture. In the center of walls, in trenches and foundations, and even under water, the indurations of cement compounds proceeds steadily, until in due time the mass acquires the hardness of stone. Lime mortar, when fat limes are used, soon gets a thin skin of carbonate formed at the surface and joints, and the very formation of this exterior skin or coating at once presents a formidable obstacle to the induration of the lower or interior layers of the mortar. These merely dry into a crumbling porous powder, with little or no strength, and which, if the air cannot reach them, are no harder in one hundred years than in a twelvemonth. Alberti states that he had seen lime in an old ditch that had been abandoned about two hundred years "which was still so moist, well-tempered and ripe, that not honey, or the marrow of animals, could be more so." What a contrast to this is presented by the fact that a week or two back, while a barge at some works upon which I am engaged in Staffordshire was being unloaded, a sack of Portland cement fell into the water; it could not be fished up for a day or two, but when recovered it had become converted into a stone-like mass moulded to the exact form of the sack.

Perhaps I shall be reminded that mortar joints are not by any means generally such worthless affairs as cement advo-

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TABLE I.—COMPARATIVE STRENGTH OF GREY LIME AND PORTLAND CEMENT MORTARS; ALSO PORTLAND CEMENT MORTAR, WITH THE ADDITION OF LIME AND LOAM.

No.	Number of tests.	Proportions.				Breaking strain on 2.25 square inches in lbs.	Breaking strain per square inch in lbs.	Ratio compared with lime mortar.	Ratio as compared with cement mortar.	Remarks.
		Sand.	C'ment	Lime.	Water					
1	17	2.00	—	1.00	1.33	61.06	27.13	—	—	Three samples of Grey lime. Water includes that required for slaking lime.
2	27	2.00	—	1.00	1.33	106 07	47.09	—	—	
3	27	2.00	—	1.00	1.33	82.00	36.44	—	—	
1	15	6.00	1.00	—	1.25	233.53	103.79	2.81 to 1	—	Cement taken from bulk in store.
2	20	8.00	1.00	—	1.66	154.80	68.80	1.86 to 1	—	
3	35	10.00	1.00	—	2.00	112.88	50.16	1.36 to 1	—	
1	70	6.00	1.00	0.50	1.50	165.31	73.47	2.00 to 1	0.70 to	Water inclndes that required for slaking the lime.
2	74	6.00	1.00	0.66	2.00	132.62	58.94	1.60 to 1	0.85 to 1	
3	85	10.00	1.00	0.83	2.50	95.27	42.34	1.14 to 1	0.84 to 1	
				Loam.						
1	21	6.00	1.00	0.50	1.00	136.80	60.80	1.64 to 1	0.58 to 1	Yellow loam, fresh dug and rather damp.
2	25	8.00	1.00	0.66	1.33	86.48	38.43	1.04 to 1	0.55 to 1	
3	19	10.00	1.00	0.83	2.00	64.50	28.66	0.77 to 1	0.57 to 1	

TABLE II.—STATEMENT OF APPROXIMATE COST OF MORTARS.

Description.	Proportions in cubic yards.				Cost of material.	Cost of labor and water.	Total cost.	Produce of mortar in cubic yards.	Cost per cubic yard.
	Portland cement at 45s. 8d. per cubic yard.	Grey lime at 14s. 6d. per cubic yard.	Loam at 2s. 9d. per cubic yard.	Sand at 2s. 9d. per cubic yard.					
					s.	s.	s.	cu. yds	s.
Grey lime mortar	—	1.00	—	2.00	20.00	6.62	26.62	2.25	11.83
Portland cement mortar No. 1	1.00	—	—	6.00	62.19	6.84	68.23	5.90	11.56
Portland cement mortar No. 2	1.00	—	—	8.00	67.69	7.80	75.49	7.60	9.93
Portland cement mortar No. 3	1.00	—	—	10.00	73.19	9.57	82.76	9.30	8.88
Portland cement and lime mortar No. 1	1.00	0.50	—	6.00	69.44	8.68	78.12	6.40	12.20
Portland cement and lime mortar No. 2	1.00	0.66	—	8.00	77.27	11.20	88.46	8.25	10.72
Portland cement and lime mortar No. 3	1.00	0.83	—	10.00	85.22	13.78	99.00	10.15	9.75
Portland cement and loam mortar No. 1	1.00	—	0.50	6.00	63.56	6.23	69.79	6.10	11.44
Portland cement and loam mortar No. 2	1.00	—	0.66	8.00	69.53	8.05	77.58	7.90	9.82
Portland cement and loam mortar No. 3	1.00	—	0.83	10.00	75.47	9.97	85.44	9.75	8.76

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cates are wont to describe them, and that even when white chalk lime or mountain limestone is used, the crystallization of the hydrate of lime round the particles of sand presents the appearance of some slight induration. I will grant that such is to a certain extent the case, but I believe it will more often be found that this trifling amount of induration is due to the sand employed in forming the mortar. Lime has the power of slowly attacking silica, even in the form of quartz, and most sands present other bases favorable to the formation of compound silicates. We thus get in very old mortars a small percentage of silicate of lime, which can only be accounted for by some such action as this. Of course, when the lime is presented with a sufficient quantity of a substance of the nature of puzzuolana, to enable it to form silicates in the work, we obtain a cement action differing but little from what would result from the use of true cements. Some writers seem to have thought that it might be cheaper, and more generally convenient, to form the cement in the work by compounding a mortar of a fat lime with the requisite quantity of calcined silicious clay; but this plan, after having been tried on the Continent, has been abandoned in favor of the mode, patented by Vicat and St. Leger, of making an artificial hydraulic lime from a mixture of chalk and clay. This manufacture is still carried on upon a considerable scale round Paris, at Issy and Meudon, and the use of pure lime, so vigorously denounced by Vicat, has since his time been to a great extent abandoned (at any rate, upon public works) in France. It cannot be said that here in England we have taken to heart the lessons we have learned, and the unscientific use of lime burned from the hard limestones of the North of England, and from the white chalk in our southern and eastern counties, still continues unchecked.

A third reason for employing cements in preference to limes is, that a method has been discovered by General Scott by which limes can be converted into cements by a very simple process, and at a very moderate cost. Perhaps you will allow me to glance briefly at this invention, as it is one imperfectly understood. About twenty-five years ago General (then Captain) Scott, of the Royal Engineers, found that a sample of grey lime, burnt in a common fireplace, with a smothered fire, had acquired properties very different from those of the same lime if prepared in a clear bright fire. He at first thought that this peculiar result was due to the formation of a subcarbonate of lime, owing to the imperfect combustion of the fuel, but subsequent experiments caused him to abandon this view, and to adopt the theory, which he ultimately found to be the correct one, that the change in the character of the lime was due to the presence of sulphur which had been absorbed from the ashes of the coal. This fact led to the invention of what was called Scott's cement, a material which was prepared as follows: Tender burnt grey chalk lime, made from a lower chalk, containing from 10 to 15 per cent. of silica and alumina (as, for instance, that of Lewes, in Sussex, or Borham, on the Medway), was re-heated to bright redness in shallow kilns or ovens, having perforated floors or hearths. When the lime was sufficiently hot, pots of sulphur were placed beneath the floors, and this sulphur was at once set fire to by the heat of the kilns. The fumes of the burning sulphur thus rose around the lime, and a coating of sulphate of lime was formed over each of the lumps. The lime was then ground between mill stones, and Scott's cement ready for use was obtained. As it appeared that this cement owed its peculiar properties to very minute quantities of sulphate of lime, intimately mixed with it, General Scott thought it might be possible to prepare it in a cheaper way, as, for instance, by sprinkling lump lime with sulphuric acid, or mixing ground lime with plaster of Paris; but though each of these plans was tried most carefully, it was found to be impossible to secure uniformity by any other than the gaseous method before described. Many years later, during the building of the 1871 Exhibition, General Scott found that if the selenitic lime, however prepared, were first ground in a mortar mill to a creamy paste, and the sand then added, a very good cement action was secured, and he made a selenitic cement, as he has termed it, from a careful mixture of ground hydraulic lime and sulphate of lime. This cement, if

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used as directed by General Scott, will bind together six parts of sand into an extremely hard mortar, and will make a good concrete with nine parts of ballast. My argument in favor of the use of cements is, therefore, greatly strengthened by my being able to point to such a material as selenitic cement.

The question of the kind of sand to be employed hardly enters into my present subject. I may mention, however, that in using cements, in order to secure their utmost strength, clean sand is eminently necessary. Sharp large-grained sand makes better work than find sand, and there seems scarcely any objection to clean sea sand, except that for internal plastering it is liable to become damp on changes in the weather, as the salt absorbs moisture. Salt sand makes stronger cement mortar than pit or river sand, provided all are equally clean.

I wish, in conclusion, to say a few words about the use of cement in concrete. In this direction I am convinced that hitherto very little has been accomplished, and we plod on here in London with bad bricks and bad mortar, as if there was no escape from a thoroughly vicious system of building, which ought to have been abandoned with the building of the Tower of Babel. Concrete making and the numerous uses of cement concrete is a subject in itself for a long paper, and I can only point to a few directions in which the applications of concrete appear to deserve attention. I am disposed to affirm—at any rate, I will do so for the purpose of argument—that as London, from its peculiar position, is and must continue a brick city, we ought, with our present knowledge of the properties of cements, to make our bricks much smaller, to serve as mere "aggregates," or, what would be better still, we should calcine our brick earth in heaps, as ballast is made, and unite this burnt clay into monolithic structures with Portland cement. I cannot perceive any legitimate argument in favor of selling under-burned, misshapen, discolored lumps of calcined clay at so much per thousand, in order to enable builders to charge £14 and upwards per rod for sticking them together into walls. Far better would it be to burn the bricks into clinkers, and then incorporate the fragments of them into solid homogeneous structures with good cement, at less than two-thirds the cost of brick work. I sincerely hope I may live to see the day when bricks will be discarded, and I trust that the New Zealanders, when they explore the ruins of London, may find it necessary to dig very deep down into the *debris* before they find any "genuine, sound, square, hard-burned stock-bricks," for the ceramic museums of the future. The days are past when the color of cements must ever be thrown in our teeth as a reproach. Mr. Lascelles has shown the possibility of so coloring Portland cement as to render it scarcely distinguishable from red brick or terra cotta, and the house he sent to the Paris Exhibition, designed by Mr. Norman Shaw, formed a new departure in concrete building. Mr. Lascelles is able to prepare mouldings and dressings in this material at a less cost than the same work in cut bricks or terra cotta. In point of natural color, selenitic cement, which is a warm buff, leaves little to be desired. Another direction in which cement concrete may be used with advantage is evidenced by the manufactures of Messrs. H. Sharp, Jones & Co., of Poole. This firm has succeeded in making excellent drain pipes of Portland cement concrete. The manufacture is a very interesting one, and as I have recently been permitted to examine the works, you will perhaps allow me briefly to describe the process. Cement of high quality is mixed with crushed pottery in the proportion of 1 of cement to about 3 of pottery. The concrete is made in small quantities in a special mixing machine, the materials being first turned over dry, then sprinkled with water from a fine rose and made into a very dry concrete. The mixture is next lifted into a hopper, which feeds it automatically and very gradually into the moulds. These are made as cylinders of sheet iron, the proper distance apart to form the thickness of the pipe, from 1 in. to 3 in., according to its diameter. This mould rotates slowly on a turn table, while an iron rammer worked up and down like a beetle, compresses the concrete into the mould as it falls from the hopper. When the pipe is full, it is wheeled away on a truck, mould and all, and stands for from 24 to 48 hours to set. When taken from the mould, the newly-made pipe is steeped

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for a week in a bath of silica, to indurate it more effectually, by the ingenious process invented by Mr. Highton, and used by the Patent Victoria Stone Company. The pipe may remain in the bath for about a week, when it is removed and stacked in the open air for some months before it is sent out for use. The Victoria Stone Company, just mentioned, make excellent paving slabs of granite chips and Portland cement. These slabs appear to be very durable, and they are not so costly as common York paving. Mr. Drake has recently shown me some interesting specimens of the marble and granite mosaic work and concrete his company are now producing. I have only now, in conclusion, to express the hope that I may have succeeded in showing that "the use of cement" is a subject well worthy of the careful attention of the architect.

In the discussion which followed, the President (Mr. Ernest C. Lee), while expressing his sense of the great practical importance of the subject treated of by Mr. Redgrave, said he was no great admirer of the homogeneous monolithic houses, the erection of which had been advocated.

Mr. W. H. Lascelles (of Bunhill row) exhibited a number of specimens of his moulded and colored concrete work, and in response to an invitation from the chair, made a few remarks about them. One moulded or coffered slab which he produced was, he said, designed by a well-known architect, as part of a new method of getting ornamental though fireproof ceilings in rooms. Iron joists were embedded in concrete, and upon these concrete-covered joists the slabs were laid direct, leaving the joists and the under surfaces of the slabs to form the ceiling of the room below, the upper surfaces of the slabs forming the floor of the apartment above. This simple mode of fireproof flooring had received the approval of several architects of distinction. The objection that such floors would be too resonant or noisy when walked upon to allow of their coming into practical use had been falsified by facts. He had built some small houses with floors of that construction, and the tenants made no complaint of noise. Such upper rooms, it should be remembered, being bedrooms, would mostly be carpeted over on the portions walked on. He was now engaged (in connection with one of the companies who made it their business to erect dwellings for artisans) in seeing whether he could not devise a floor of that kind for such buildings which should be cheaper as well as better than floors of the ordinary kind. The fireproof qualities of the floor had been tested at the Croydon Exhibition of the Sanitary Congress, with conclusive results in their favor. A remarkable property of the concrete material of which these floors were made was that it would bear the driving of nails into it, not only without cracking but would hold them most tenaciously. So well recognized was this quality of the material becoming, that bricks or blocks of it were now used for building into interior walls, instead of wood blocks, for fixing the joiners' work to. The first discoverer of this kind of concrete was the late Mr. Matthew Allen, but it had been much improved upon from time to time, and it had now been found possible to impart to it a good and durable red color. It could be moulded to any form, and was hardly distinguishable from, though much cheaper than, the best cut brick-work.

Mr. Drake thought that the difficulty of giving concrete work a good aspect externally was now being solved. It had been very difficult to obtain reliable coloring matter for concrete work, and of late he had turned his attention to making the natural surface of the material sightly and even beautiful in itself. Many of the aggregates used, such as marble and granite chippings, were beautiful in themselves, and he had succeeded in making a concrete with a smooth and semi-polished surface, in which the pieces of marble and granite forming the aggregates were shown in their own colors, forming a sort of natural mosaic work. (A door in this material, made for the Theatre Royal, Manchester, was exhibited.) The same material was also capable of large and effective use in the shape of small slabs or tiles for flooring purposes.

Mr. J. S. Quilter, in proposing a vote of thanks to Mr. Redgrave for his paper, said the more experience he had of the use of Portland cement, the more reason did he see to use it more largely than ever, and he was glad to see that its use

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was becoming common on the better class of building estates in the neighborhood of London. On an estate at Streatham (entirely a clay district) houses were being carried up of concrete made of Portland cement and of burnt clay ballast in the manner suggested by Mr. Redgrave.

THE PREVENTION OF FLOODS.

From "The Engineer."

We have repeatedly called attention to the need for beneficial interference with the principal rivers of England; and we are glad to find that a chance exists that steps will be taken to mitigate a growing evil. A very influential deputation was introduced by the Duke of Bedford to Mr. Dodson, the President of the Local Government Board. The object of the interview was to request the Government to bring in a bill for the better regulation of rivers. It is to be regretted that this was not quite so definitely stated as it might have been, but Mr. Dodson understood his visitors. He could make no promises for the Government as a whole, but for himself he assured the deputation that the views expressed by the various speakers, and the statements which they had made should be brought before his colleagues, and would no doubt "have the earnest consideration which the gravity of the subject and the importance and number of those interested make it deserving of at their hands." The style in which the promise is worded is open to criticism, but the matter is to the point, and the members of the deputation had no reason to be dissatisfied with it; yet we fear that a long time will yet elapse before anything of much value is really effected in a practical way to improve our rivers. The deputation, however, have done one good thing. They have at last clearly indicated the amount of pecuniary loss caused, we shall not say by floods, but by the absence of all attempt at regulating the great streams which are supposed to drain this country. In dealing with this aspect of the question they were necessarily brief, for Mr. Dodson's time is valuable; but enough was said to convince the most incredulous, we should think, that the prevention of floods is a matter not of local interest but of national importance. Mr. Magniac, M.P., speaking for Bedford and of the Ouse, said that in his own locality 10,000 acres had been flooded this summer. One farmer paid rent for land he had not seen for two years. Mr. Coote, of Huntingdon, drew a frightful picture, which we have reason to believe was in no whit exaggerated, of the suffering and loss caused in his district by floods. Mr. Sergeant urged that in eighteen miles of the Severn Valley £63,000 worth of food had been destroyed. In the county of Worcester one landowner had lost £4000 a year, and so on. No doubt the pecuniary loss must be counted by hundreds of thousands of pounds per annum, and the mischief does not end there; for, besides not a few deaths caused by drowning, healthy districts are rendered insalubrious; fever and ague are to be found where they ought to be utterly unknown, and the young and the aged are hurried out of the world by the combined effects of damp and bad drainage. Thus in Huntingdon the death rate has been doubled.

We have heard it urged that the floods are not worse now than they used to be, and that if they are it is because of exceptionally bad weather. It is well that this theory should be demolished as soon and as thoroughly as possible. There can be no doubt that subsoil drainage not only greatly augments the work thrown on rivers, as we have explained in our impression for Nov. 5th, but that it also does much to raise the beds of the rivers into which storm waters are discharged. The continuous operation of natural forces tends to fill up the bed of every river, each tributary bringing down its own contribution of detritus. The tendency of the river current is to deepen the bed by scour. In some cases these forces very fairly balance each other; but the moment man begins to

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work the balance is overset. If on the one hand he dredges and straightens the stream, he augments the velocity of the current, and causes more scour. Then the tendency will be toward the natural excavation of the river bed. If, on the contrary, he drains the land over the area of the watershed supplying the river, then will the tendency to silt up become predominant, and the bed of the river will gradually rise. Mr. Magniac gave some admirable illustrations of this truth to Mr. Dodson. Every fresh flood brought something down the Ouse which stopped somewhere and caused an obstruction. Thus at Bedford a fallen willow tree had produced a sandbank. At particular places where the river used to be deep, it can now be crossed dryshod in summer. In English rivers the tendency to silting up is not—or rather was not before the days of extensive subsoil drainage—manifested to anything like the degree to which it is to be seen on the continents of Europe and America. The floods at Zegedin afford an illustration of what we mean. The melting snows in the Carpathians carry with them great quantities of silt, which gradually raises the level of river beds. The people dwelling on either bank, instead of dredging, make embankments to keep back the water, and as silting and embanking have gone on steadily for generations, the rivers now flow several feet above the level of the surrounding country. When a dam gives way, ruin and death on a frightful scale ensue. In process of time, unless proper precautions are adopted, such rivers as the Ouse will cease to have any proper beds. and will wander over the face of the country, finding an outlet to the sea where they can. All sluggish streams tend to form marshes, and this fact should never be forgotten.

In dealing with the regulation of rivers question, Parliament will do well to remember that the flood evil is a growing evil. Year after year matters will be worse and worse. The area flooded will be increased in dimensions. The quantity of land permanently submerged will be augmented. The waters will "come out" sooner in the year and will remain longer. Small local thunderstorms will produce local floods, and the pecuniary loss to the nation will grow larger and larger each year. It is essential, therefore, that Parliament should take the matter in hand without delay. It is not at first sight easy to see why it it has not been taken up long since; and this fact has been used as an argument against parliamentary interference. The evil, we have been told, is not really so great as it is said to be, or it would have been found intolerable long since. A little reflection will, however, suffice to prove that this is a specious and useless argument. It is a very serious matter, in the first place, to attempt the regulation of a large river on a comprehensive basis. None but highly trained and competent engineers can carry out such a work successfully. Again, the cost must be great; and last, and certainly not least, the determination of the legitimate incidence of the cost of the regulation works constitutes a complex and troublesome problem. Those living on high ground at each side of a river assert that the floods do not hurt them, and Jones cannot see why he should be taxed to prevent Robinson's farm being flooded, Jones the while willingly remaining blind to the fact that it is not the rain which falls on Robinson's farm which floods it, but that which fell on Smith's, Brown's and Jones', and a great many other farms standing at a higher level or lying further up the stream than Robinson's farm. We are not sanguine enough to expect that the tribe represented by Jones will ever be brought to see the propriety of paying anything for the help of the class represented by Robinson, and for this reason the whole matter must be dealt with on a very wide basis. The regulation of rivers must be regarded as the business of the nation, and not of individuals. As soon as the subject is brought before Parliament some person or persons who care nothing about floods will urge that Parliament cannot legislate on the subject because it knows nothing about it. Parliament will admit the truth of this statement, and then a select committee will be appointed, and scores of witnesses will be examined, and a year or two will pass and nothing will be done; and, finally, the committee will get all its ideas concerning floods and the way to prevent them jumbled up together, and we shall have a report which will not in

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any way elevate the standard of Parliamentary knowledge, or enable Parliament to legislate on the subject with more prudence or skill than it possessed before the inquiry was carried out. The proper course to be pursued by the Government is to appoint a commission of three engineers of the highest standing and greatest skill in river regulation. These gentlemen will then visit and examine the principal river valleys of the kingdom, obtaining information on the spot, and in a very short time they will be able to answer one or two very simdle questions, which may be thus stated. Can the floods in the river be reduced by regulating its course? What is the area implicated in the production of the existing floods? What is the area now flooded every year? Is the *regime* of the river becoming better or worse? In general terms, about how much will the necessary works cost? Answers to all these questions could be obtained in less than three months by a competent commission of experts, aided by a sufficient staff, who would be on the spot to see for themselves, and who would be able to appreciate the statements made to them. The Government could then go to Parliament with something like a definite scheme. It could say, "this work can be done to advantage; it will cost so much; the money will not be wasted; it must be raised on such, and such, an area, and will represent so much in the pound sterling annual value of the land implicated." The cost of an investigation would not be one-fourth of that of a select committee, which could be called upon to hear counsel, and investigate the rights of every petty little mill owner on the river's brink. There can be no doubt that at the present time the interests involved in water rights and so on, are all mixed up in a deplorable muddle. Mr. Magniac, dwelling on this fact, cited the case of the town of Turvey in Bedfordshire: "The state of things," said Mr. Magniac to Mr. Dodson, "is frightful. The bed of the river belongs to one man, the right bank to a second, and the left bank to a third proprietor; and all the while the bed of the river in the proper sense has no practical existence." Under such conditions any measure must be sweeping if it is to be effectual. River beds should, indeed, be regarded not as the property of individuals, but of the nation; and if this be considered to be going too far, care should be taken that vested rights should not become vested wrongs to other men. A little mill weir may now cause the flooding of hundreds of acres of valuable land. Time was when the mill was, perhaps, worth more than the land, but the land has been reclaimed and improved, and is worth ten times as much as the mill. Why should not the millowner be paid a fair price and sent about his business? If Parliament is not prepared to deal with this matter with a strong hand, and do some injustice, that it may remove what is day by day approaching more and more nearly to the condition of an intolerable evil, then it would be better to leave the subject untouched. A grand opportunity is presented for useful legislation; but the opportunity will be entirely lost if Parliament is disposed to split hairs concerning the rights of millowners and certain other water-side proprietors.

COFFERDAMS IN FLOODED RIVERS.

By M. LANTEIRES.

From "Abstracts" of the Institution of Civil Engineers.

The author describes the erection of masonry piers or coffer-dams for two bridges over the Garonne at Muret and at Cazères, during the time of the high floods of that river in 1875, when three out of four coffer-dams were carried away. The bed of the Garonne, throughout the greater part of its length, consists of a tufa, or clayey sandstone, composed of schistose sand agglomerated by an argilo-calcareous gangue. These coffer-dams were built in the ordinary way with wood piles 10 inches in diameter, driven for 19 to 31 inches into the tufa. In driving the piles the tufa was splintered and broken up,

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so that the hold of the piles was very insufficient, and the buoyancy of the wood-work made it easy for the flood-stream to carry it away. In rebuilding the coffer-dams, wood piles were used only at the meeting of the ends of the longitudinal timbers or binders, the intervening panels of sheet-piling being supported by bar-iron piles 2.38 inches diameter clamped between the binders. The wood piles were 12 inches in diameter, provided with shoes with lance-like terminals 20 inches in length, driven into the tufa at the bottom of holes bored about 3 feet deep, with a 10-inch spiral augur. At about this depth boring was generally stopped by meeting a hard substratum, into which the pointed shoe only was driven. The bar-iron piles were driven about 6.5 feet into the tufa without materially breaking it. The piles were from 5.24 to 6.3 feet apart, and were 27 feet in length. The sheet-piling was 4 inches thick, two rows only of horizontal binders about 7.5 inches square being used. The double rows of piling of these dimensions were 5.24 feet apart, the interspace being filled in with tempered clay let down in blocks and well rammed. The dams so made, though light, were successfully used in completing the work. A statement of the cost of the dams in detail is given.—(*Annales des Travaux Publics.*)

THE QUANTITIES OF WATER IN GERMAN RIVERS.

From "Nature."

An attempt has recently been made by Herr Graeve (*Der Civil-Ingenieur*) to determine the amount of water in German rivers and its apportionment in different seasons, a question very important for navigation, and also of much scientific interest. His research comprehends the chief rivers of Germany, excluding the Danube, which begins to be navigable only outside of Germany, and including the Vistula and the Memel. He first calculated, from the mean heights of water, the quantities of water flowing out per second, and he adds a table in which the amount of outflow is shown in relation to the extent of the corresponding river territory. When the amount of outflow per 100 sq. km. of the region of precipitation is calculated the following values are obtained:—(1) the Rhine at Coblentz above the Moselle mouth delivers per 100 sq. km. of land 1.070 cub. m. of water in a second; (2) the Weser at Minden, 0.826 cub. m.; (3) the Elbe at Sorgau, 0.579; (4) the Elbe at Barby, 0.554; (5) the Oder at Steinau, 0.460; (6) the Oder below the Warta mouth, 0.413; (7) the Warta near its mouth, 0.344; (8) the Vistula at Montau Spitz, 0.538; (9) the Memel at Tilsit, 0.600.

From these numbers it appears (*a*) that the average outflow of different rivers, from equal portions of their territory, differs much more than is usually thought, for in the Middle Rhine it is about three times, in the Middle Weser two and a half times, and in the Middle Elbe, as also in the Lower Vistula and Memel, more than one and a half times as much as in the Lower Warta. On the whole, it decreases from the Rhine to the Warta, and from the latter increases again to the Memel. (*b*) In one and the same river the quantity from equal portions of land seems as a rule to decrease down stream. (*c*) All calculations of quantity of outflow in streams, based merely on extent of the region of precipitation, must, as a rule, give incorrect results.

It was important to try and determine the relations of the quantity of outflow to the rainfall of the corresponding regions, and Herr Graeve, doing so by a method which he describes, obtained the following percentage numbers, corresponding to the above series of rivers:—(1)=38.5 per cent.; (2)=37 p. c.; (3)=30 p. c.; (4)=28.5 p. c.; (5)=27.2 p. c.; (6)=21.4 p. c.; (7)=21 p. c.; (8)=29 p. c.; (9)=32.5 p. c.

From this the following conclusions (briefly) are drawn:

(*a*) The percentage proportion of the amount of outflow to the rainfall differs

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very considerably in these several rivers, though far less than the amount of outflow from equally large regions of these rivers; hence the differences of the latter can be due only in part to differences in the rainfall.

(*b*) The percentage decreases from the Rhine to the Warta, and increases again from the latter to the Memel. In one and the same river a decrease is perceptible down the stream, at least so far as the phenomena in the Oder and the Elbe are general.

(*c*) Since in a mountainous region a greater part of the atmospheric precipitates is carried off by rivers than in the plain, the steady decrease in the percentage proportion of outflow to rainfall, in the direction from the Rhine to the Warta, must be primarily attributed to the increasing flatness of the region; so too must the decrease of the percentage down stream. The influence of more or less wood on the land could not be precisely determined.

(*d*) The marked increase of the percentage in the direction from the Warta to the Memel cannot be explained by the orographic conditions of the region of precipitation, because this region in the case of the Memel is not at all hilly, and in that of the Vistula only a little more hilly than that of the Warta, but since the amount of the evaporated part of atmospheric precipitates is considerably influenced by the mean temperature of the region of precipitation, and this in the region of the Vistula and the Memel is lower than in that of the Warta, the increase of percentage in question from the Warta to the Memel must mainly be attributed to climatic conditions.

(*e*) While the percentage in question must be chiefly governed by orographic and climatic conditions, there can be no doubt that other factors also act, *e. g.*, the relative amount of moisture in the air, which influences the degree of evaporation, and in general must decrease from the rainy Rhine region to the dry region of the Warta; further, the amount of plantation, which in the regions of the Vistula and Memel is larger than in those of all other German rivers; lastly, the nature of the ground, allowing more or less passage to the precipitates; the influence of all these factors, however, cannot be proved with the same certainty as the orographic and climatic conditions.

A comparison of the amounts of outflow in different years shows that in individual rivers more important differences occur than are generally supposed, that these differences in rivers of different character and unequal force are very different in amount, and that in the same river they decrease down stream.

With regard to the difference in amount of outflow in the various seasons and months, the following average values were obtained. The amount of outflow in winter (from the beginning of November to the end of April) is to that of summer, at the parts of the stream examined, in the Rhine as 1 : 0.922, in the Weser as 1 : 0.434, in the Elbe as 1 : 0.467, in the Oder as 1 : 0.525, and further down stream as 1 : 0.522, in the Vistula as 1 : 0.486, and in the Memel as 1 : 0.389. A better idea of the regularity of the quantities of outflow is given by the relations of these for the dryest and the wettest month of the year; in the case of the Rhine this ratio is 1 : 1.458, in the Weser 1 : 4, in the Elbe 1 : 5.238, in the Oder 1 : 4.5, and further down 1 : 3,68; in the Vistula 1 : 4.19, and in the Memel 1 : 4.51.

The causes of the difference in the ratio of the largest and least monthly amounts of outflow must chiefly be sought in the presence or absence of collecting basins, as also in the orographic and climatic conditions. In the Rhine all those factors combine which affect the regularity of outflow. It possesses in the Swiss lakes large reservoirs; its river region comprises mountains of various height, and plains, so that the melting of the snow must occur at very different times of the year. The Memel also possesses reservoirs in its marshes, and its region is perhaps better wooded than that of the other streams of Germany; but the long and hard winters cause an accumulation of large masses of ice and snow which melt suddenly and almost simultaneously in the whole region.

Herr Graeve takes up various other points, which have a practical bearing on navigation, but for these we must refer the reader to his memoir. He remarks, in concluding, on the desirability

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of comparing the conditions of outflow of German rivers with corresponding data for other European rivers, though at present the scanty and incomplete character of the data at hand render such inquiry scarcely practicable.

A PERMANENT STANDARD CELL.

By MAJOR R. Y. ARMSTRONG, R.E.

From Papers of the Royal Engineer Institute.

THE following description of a very simple standard cell of nearly unlimited endurance, and not likely to be injured by accident, may be interesting to those who cannot conveniently procure the more accurate standards now made.

It can be made by a novice without difficulty, and gives, when used with an electrometer, results within one per cent. of the truth.

In two porcelain or earthenware chambers, separated from each other by a *non*-porous partition, are placed the zinc and copper elements respectively. A semi-saturated solution of sulphate of zinc is poured into the compartment containing the zinc element, and a saturated solution of sulphate of copper is poured into the other.

The cell may remain in this condition apparently for years without undergoing any change: it is merely necessary to add distilled water to the solutions from time to time, as their level falls through evaporation, and to prevent the sulphate of copper from creeping up the sides of the cell.

When it is desired to use the cell as a standard, a string of cotton or twine is dipped in water and used to connect the liquids, which are thus connected electrically, but do not mix for hours. At the conclusion of the experiment, the string is removed and thrown away and a fresh one used next day.

After employing some of these cells for a couple of years no traces of copper could be detected in the zinc cell.

The electromotive force varies under conditions which I have not determined from 1.083 to 1.065 ohms; that is only 0.83 per cent. from the mean value of 1.074. It is unaffected by raising the temperature to boiling point; and I have not observed that action of light produces any alteration.

A number of these cells when first made up were within an extreme range of 1.069 to 1.077 ohms.

It is probably desirable to employ commercially pure metals and salts, although I have not found that cells prepared with the above precautions differ in any way from those made up with ordinary commercial materials.

As I have already stated, this is not in its present condition an accurate standard, but it is a very convenient one for work not requiring greater accuracy than can be obtained by its means, especially if it can be checked at starting by some recognized standard.

This cell may be used with a potentiometer, provided that a reflecting galvanometer be employed with a connecting key, and that the contacts be made as short as possible, until the resistances have been so adjusted that there will be no deflection of the galvanometer on a more prolonged contact being made.

The results obtained with a condenser are not very accurate, as even the current required to fill a capacity of about $\frac{1}{8}$ microfarad appears to lower the EMF of the cell at the moment abont 2%.

N. B.—From experiments made during the past two months I think that the value of 1.07 volts will not differ more than 0.5% from the correct value. The previous experiments were made with a zinc wire soldered to the zinc element and a copper wire to the copper element, and the variations made have been caused to some extent by damp at the junction of the copper lead with the permanent zinc wire; at any rate, since a copper wire was *soldered* to the zinc element the EMF has only varied from 1.065 to 1.075 volts. The mean value of which is 1.07 volts, which should be taken as the actual value.

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SIGNALING BY MEANS OF SOUND.

By E. PRICE-EDWARDS

From the "Journal of the Society of Arts."

In a recent trial it was argued that the transmission of verbal sounds, *i. e.*, of the sounds produced by articulate speech, should properly be regarded as signaling, but in connection with the observations which I shall offer to you this evening, I prefer to accept the view of the learned counsel on the other side, and to avail myself of his retort to the effect that, although my remarks are in a sense transmitted to distant hearers in this room, yet it would be an obvious misapplication of terms to say I was signaling to those hearers. I think it necessary to make this preliminary observation, because it is beyond my purpose, on this occasion, to deal with those methods of conveying oral sounds which have been so marvelously developed during the last few years. The value to mankind of these astonishing discoveries cannot yet be fully apprehended. We are evidently on the threshold of great changes, as regards means of carrying messages; the steam locomotive, the penny post, even the telegraph system itself, are threatened by the possibility of other more simple and direct methods being brought into practical operation, by means of the telephone, the phonograph, the microphone, and last, but by no means least, the photophone, of which so brilliant a description was recently given in this room by its talented discoverer.

But these are not the instruments which minister to the practice of signaling, in the sense in which I desire to place it before you.

A signal is defined as a sign which has been agreed upon to give notice of some occurrence, command, or warning, to a person or persons at a distance. The necessity for such means of conveying intimations is too obvious to be dwelt upon. I need hardly recall to you the system of signaling by beacon fires, which was so extensively in use in early days; nor need I remind you that those crude methods of ancient times have, in the process of time, been generally superseded by simpler and more effective means. The splendid lighthouses on our coast, which convey guiding and warning signals to the mariner; the colored and other lights used for vessels at sea, and also for railway purposes; flashing signals, employed for communicating between H. M. ships at night, and for other purposes, are all suggestive of ancient practice, although more elaborate and perfect, and suited to modern requirements.

Flags, again, have for centuries been used as emblems and signals for the conveyance of messages across intervening spaces. For military purposes they continue to be used, and for service at sea they have been so effectively utilized that there now exists an international code, generally adopted by all maritime nations, which permits conversation to be carried on between ships of all countries, the combinations of eighteen flags and three pennants being the signals whereby messages pass between mariners who do not even understand each other's language.

The semaphore was once much used for military signaling, but it is now almost entirely employed in connection with the railway service.

For storm warnings, drum and cone shapes are hoisted at prominent points on the coast, to indicate the approach of bad weather.

And I may allude to the valuable invention of the heliograph, or sun-flashing mirror, which rendered such conspicuous service in the late wars in Afghanistan and South Africa, by which signals can be flashed across an intervening space of from 50 to 100 miles.

Finally, signals of distress are made on board ship by the firing of rockets, and by flames on the deck.

It will be observed that the examples of signaling to which I have alluded are those which appeal to the sense of sight only. Signals, being intended for

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human purposes, are, of course, dependent upon human perceptions for their comprehension. Sight, as we have seen, is made available. I do not think any definite system has been developed by which signals can be transmitted through the medium of taste or touch; nor has science yet indicated any method of utilizing the sense of smell for the conveyance of definite messages, although, in the vincinity of foul places and decomposing refuse, odoriferous signals are generally wafted abroad, plainly indicating the presence of germ-laden gases, and silently bidding us beware.

But the necessity for transmitting signals has been found to exist at times when sight is unavailing, and then the sense of hearing naturally suggested itself as the perception which should be appealed to.

Thus we arrive at the branch of the subject which I have ventured to bring under the notice of the members of the Society of Arts this evening; and I think it proper to say, that in preparing this paper, I have sought rather to make it a record of facts than anything like a speculative inquiry, and have encouraged myself to hope that my efforts may possibly be the means of bringing to bear upon the subject the scientific and mechanical intelligence of many, in such an audience as this, and who may assist in the valuable work of developing the means of making sound signals fulfill their purposes with accuracy and precision.

The effective employment of sound signals appears to be chiefly dependent upon two factors, the facilities offered by the atmosphere as a vehicle of sound, and the human capacity for hearing and distinguishing sounds of different characters. It will, perhaps, be convenient to regard first these two points, and afterwards to deal with the application of sound signaling for various purposes, and the different kinds of instruments used to produce the sounds.

It is hardly necessary, before such an audience as this, to attempt an explanation of the general laws governing the propagation of sound; and, in the presence of so eminent an authority as the learned professor who has so highly honored my subject and myself by presiding this evening, to do so would show some temerity on my part. It is, nevertheless, necessary for me to put before you briefly various considerations relating to sound transmission, which have a direct bearing upon the matter in hand, but is only proper for me to observe that in this respect I must borrow the thunder of your learned chairman, and place before you results obtained through his patient investigation, judicial weighing of evidence amid conflicting theories, and unstinted expenditure of time and personal comfort.

The atmosphere is the vehicle for transmission of sound with which we are this evening concerned. Water is an excellent medium for sound traveling, and the possibilities which have from time to time been suggested in regard to it, require only the attention of inventive genius to bring them within the range of practical reality and utility. But as at present the atmosphere is the only medium which is practically available for the transmission of sound signals, it becomes important to know whether some conditions are more favorable than others for its passage.

It is evident that there are various influences which may be supposed, in one way or another, to affect the transmission of sound. Wind has always been known as a most powerful agent in intercepting and even diverting it. Fog, snow, and rain, have also been regarded by many as serious obstructions, while it has long been popularly consdered that a bright, warm, sunshiny day, with little or no wind, was exceptionally favorable for the traveling of sound. These views, it may be said, have grown up as the result of general expectation rather than of scientific observation; but the development of signaling by means of sound has necessitated a more exact inquiry, than has hitherto been made, into the general subject of sound transmission, and the result has been that some of the old theories have been considerably shaken, if not overthrown, while new ones have been set up.

In the years 1873 and 1874, an investigation was carried out, at the instance of the Trinity House, with the object of obtaining some definite information as to the relative merits of sound-producing instruments, and also of ascertaining how the propagation of sound was af-

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fected by different meteorological phenomena. Professor Tyndall, as the scientific adviser of the Trinity House, conducted the investigation, aided by a Committee of the Elder Brethren, and some officers of the Corporation. The experiments were extended over a lengthened period, observations being made in all conditions of weather, and repeated over and over again, in order to eliminate error; and the information gained thereby is of the highest interest and importance.

The results are stated at length in the third edition of Dr. Tyndall's book on "Sound," but may be popularly summarized as follows: That neither rain, hail, snow, or fog, has any sensible power to obstruct sound. From this it is most satisfactory to know that, at those times when a sound signal might especially be of service, the sound is not likely to be obstructed in its passage. That the real obstructors of sound are—first, the wind; and, secondly, what Dr. Tyndall has named acoustic clouds. These clouds have nothing to do with ordinary clouds, fogs, or haze, and may arise from air currents differently heated, or from air currents differently saturated with vapor, and they often exist on days when the atmosphere is in a very transparent condition. The obstruction is caused by the sound, intercepted by the acoustic clouds, being wasted by repeated reflections. In short, it is now established that a bright clear day is not necessarily the best for hearing distant sounds, and that on a day of dense fog it is more than probable that no obstruction is offered to the passage of sounds.

I must not omit to mention that experiments of an elaborate nature, in respect to the propagation of sound in the atmosphere, have also been made under the auspices of the United States Lighthouse Board, with results mainly corroborating those obtained in the Trinity House trials. In one respect, however, the late Professor Henry, who was at the time Chairman of the United States Lighthouse Board, differed from Dr. Tyndall, viz., in regard to the theory of acoustic clouds, and their resultant aerial echoes. Professor Henry's explanation of the obstruction of sound in clear weather, and the echoes, is founded upon the asserted existence of upper and lower currents of air, the tilting up of the sound wave, and the reflection of the sounds from the surface of the sea, or the crests of the waves. From this last explanation, Professor Henry seems to have receded before his death. Into the details of this purely scientific controversy, it is not necessary to enter; but it may be stated, as a matter of fact, that observations at the South Foreland, and the explanations given of them by Professor Tyndall, have been, one and all, illustrated and confirmed by strict experiment.

One other point may appropriately be alluded to here, viz.: as to the nature of the sound which is most readily propagated through the air, and which, therefore, is most effective for signaling purposes. It appears that what Mr. Alexander Beazeley (who very ably treated this subject of coast fog-signals some years ago) has termed "effective sound range," is made up of two factors, viz., intensity and pitch. It is tolerably well established that initial intensity is the first thing needful, and initial intensity depends upon the actual force employed in creating the sound waves. With suitable apparatus, and an effective application of very high power, there is little doubt that sounds of overpowering loudness may be produced. But the effective range of sound appears to be also controlled by its musical pitch. The short waves of a very shrill or high-pitched sound may appear extremely powerful and effective to observors in the immediate vincinity, but their energy seems to be quickly dissipated, and the sound fails to be appreciated effectively at a distance. Again, the long undulations of a very low-pitched sound do not apparently often reach great distances. It may be that this kind of movement is more readily acted upon by opposing influences, such as reflection or diversion. But, for practical purposes, it seems that the pitch best adapted for signaling lies about the middle of the scale of sound. With sound, as with light, there are wave motions above the highest pitch intelligible to the human ear, and below the lowest sound audible, and it may be, that the nearer sounds approach the limits of human apprehension, so they tend to become less appreciable. In addition to this, it has been found that the atmos-

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phere exercises a selective influence, and, within certain limits, will, under some conditions, favor the transmission of the shorter waves, or high-pitched note; while, at another time, it may be found that the longer waves of a low pitched note have the advantage.

Speaking generally, the range of sound seems to be attended with much uncertainty. It is popularly supposed that if a sound, at any one time, is heard ten or fifteen miles, it must necessarily be an exceedingly powerful sound. Now, this does not follow as a matter of course. The variability of the atmosphere will throw out any calculation made upon such an hypothesis. In the experiments at South Foreland, in calm, clear weather, one of the instruments was, on a certain day, heard at a distance of 16½ miles, but on another day, with apparently identical weather, the same instrument was heard at only 2½ miles distance. Obviously, it is no satisfactory test of a good signal that on one occasion it had a great range—sounds comparatively small and weak have at times been audible at long distances—and, therefore, I need not trouble you now with instances of this kind. The true test of a sound signal appears to be that it shall, under all conditions of weather, be uniformly effective at a short distance—say two miles.

I referred just now to what, perhaps, I may speak of as the sound spectrum, and to the limits of human capacity in regard to hearing sounds. Now, with the development of signaling by means of sound, I am not sure that the human capacity for hearing and distinguishing sounds of different kinds has received the consideration which it merits. Let it be granted that you have instruments capable of producing sounds of great power; let it also be granted that the signals appear to be distinctive and easy of comprehension, you will, I fear, still find very many people in the world, incapable of availing themselves of such signals, either by reason of whole or partial deafness, or inability to appreciate differences in sounds. Now, the question almost naturally asserts itself, cannot something be done to assist the ear, or, at any rate, the perception of sounds in the air. This seems to be the complementary side of the general question, to which but little attention has been given. In regard to visibility, you have telescopes and binocular glasses, by means of which a distant object can be brought more plainly into view. But nothing of any real value has been done to assist the hearing. The old-fashioned ear-trumpet for deaf people is little, if at all, improved. Some years ago, an effort was made in this direction by a gentleman from Glasgow, who devised what he termed a phonoscope. This instrument consisted of a sort of metal helmet for the head, with an opening like the bent cowl of a chimney, which could be directed towards any point required. This cowl was supposed to act as a sort of ingatherer of sounds, which were conveyed to the ears by two small tubes, each terminating in a button, intended to go just inside the ear. The faults of this apparatus were, first, its cumbrousness, and, secondly, the remarkable way in which all the ordinary small noises around were collected and magnified into large ones, which, combined with other sounds hitherto unheard, created a general uproar in the ears. The object this gentleman had in view deserved greater success than it obtained. He wished to assist the mariner in picking up and locating a distant sound; and, although his apparatus acted so well that it picked up noises of all kinds, and somewhat bewildered the sense of audition, yet I venture to say that if any one were to accomplish successfully what this gentleman so perseveringly attempted, a very great public benefit would be brought about. I do not mean to convey that what is specially wanted is an improved ear-trumpet for deaf persons, but rather, an instrument intended to aid people with fair hearing, or to render sounds, in some way, more easily perceptible. The late Professor Henry, of Washington, in carrying out his experiments, devised what he termed an artificial ear, by which the relative power of different sounds could be determined at short distances. This instrument consisted of an arrangement by which sand, on a stretched membrane, assumed certain definite forms, or was more or less agitated, in response to different sounds. As a phonometer, at short distances, this instrument appears to have been fairly effective, but it does not meet the want

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which appears to me to exist. With the growing use of sound for various purposes, there is scope for inventive genius to produce a phonoscope, which shall be capable of assisting the listening ear in a manner analogous to that by which a telescope aids the seeing eye.

The following is a general statement of the chief purposes for which sound signals of different kinds are in practical operation:

1. *Railways.*—Whistles of locomotives and explosives as fog signals.

2. *At Sea.*—For merchant ships, the international regulations for preventing collisions at sea prescribe, as a compulsory requirement, that in fog, mist, or falling snow, whether by day or night, the signals described as follows, shall be used:

(*a.*) A steamship, under way, shall make, with her steam whistle, or other steam sound signal, at intervals of not more than two minutes, a prolonged blast.

(*b.*) A sailing ship, under way, shall make, with her fog-horn, at intervals of not more than two minutes, when on the starboard tack, one blast; when on the port tack, two blasts in succession; and when with the wind abaft the beam, three blasts in succession.

(*c.*) A steamship and a sailing ship, when not under way, shall, at intervals of not more than two minutes, ring the bell.

And, as an optional proceeding, that a steamship, under way, may indicate her course to any other ship which she has in sight, by the following signals on her steam whistle, viz.: one short blast to mean, "I am directing my course to starboard." Two short blasts to mean, "I am directing my course to port." Three short blasts to mean, "I am going full speed astern." A gun fired at intervals of about a minute is one of the authorized signals of distress at sea. In the Royal Navy the above regulations are also in force, but, in addition, Captain Colomb's system of sound-signaling is employed in fog, for the purpose of communicating between H. M. ships. Guns were formerly in use as fog signals, but are seldom if ever employed now.

3. *The Army.*—The only sound signals systematically employed appear to be those made with the bugle.

4. *Coast Fog Signals.*—By far the most important development of sound signals is in connection with the lighthouse and coast-marking service. The most powerful lights are unavailing at night if enshrouded with fog, and, by day, buoys, beacons, and other marks and signs of the sea, are then rendered useless. The necessity for sound signals to do duty at such times for the obscured lights and hidden sea-marks, has brought about the development of a system of coast fog signals, in which development, so far as the English coast is concerned, the Corporation which I have the honor to serve, aided by your distinguished chairman, Mr. James N. Douglass, the Trinity House engineer, and others, have had a large share. The Commissioners for Lighthouses in Scotland and Ireland, aided by their respective engineers, have also taken vigorous measures for guarding their coasts with fog signals when necessary. It is proper, however, to observe that the lighthouse authorities in the United States took up the matter practically before it engaged much consideration in this country, owing to the east coast of America being in an exceptional degree liable to the visitation of fog, by which the coasting traffic was seriously inconvenienced; and the necessity arose for something to be done whereby the difficulty might be obviated. The ready genius of the country was not long in coming to conclusions, and although some kinds of sound signals, such as bells, gongs, &c., were employed in Europe, the Americans first brought into use Brobdignagian trumpets, whistles, &c., to which I shall refer in due course.

We will now pass on to consider the different kinds of instruments employed in connection with the various purposes to which I have referred.

Bells.—Bells, from the earliest times, have been employed to convey intimations by means of sound. Their chief uses in olden times have been summed up in the following:

"Laudo Deum verum, plebem voco, congrego cherum,
Defunctos ploro, pestem fugo, festa decoro."

In these days churches have not a monopoly in regard to the use of bells. The town crier, the muffin seller, the railway porter, and many others signalize themselves by the ringing of bells

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With these, however, we are not concerned, unless we may express an opinion that in some of these cases it would be an addition to the public comfort if they were suppressed.

The present regulations for preventing collisions at sea require that, in fog, mist or falling snow, "a steamship and a sailing ship, when not under way, shall, at intervals of not more than two minutes, ring the bell." These regulations are international, but the Turkish Government have objected to the use of bells as fog signals on board Turkish vessels, on the ground that it is against their religion to use bells on board ship; and, therefore, in all cases where the regulations require a bell to be used, a drum will be substituted on board Turkish vessels.

As warning signals, bells have been employed from a very early date. It is impossible to say when, or where, the first bell was put up to assist mariners; but we may quote the often-narrated tradition, handed down by an old writer, respecting the Bell Rock:

"By east of the Isle of May, twelve miles from all land, in the German Ocean, lyes a great hidden rock, called Inch Cape, very dangerous for navigators, because it overflowed every tide. It is reported in old times upon the saide rock there was a bell fixed upon a tree or timber, which rang continually, being moved by the sea, giving notice to the saylers of the danger. This bell or clocke, was put there and maintained by the Abbot of Aberbrothock; and, being taken down by a sea pirate a yeare thereafter he perished upon the same rock, with ship and goodes, in the righteous judgment of God."

The story, it is true, is only supported by tradition, but it serves to show that the notion of marking a hidden danger by a sounding bell was certainly in existence—if not practically applied—at a very early period. We know it was practically applied at Poolbeg, in Ireland, in 1811, and at the Bell Rock, in Scotland, in 1812; and we also know that, up to the year 1860, bells were established, to be sounded in foggy weather, at many other lighthouses on the coasts of Great Brrtain and Ireland, and of France, the United States, and other countries, many of which continue to be sounded at the present day. These bells vary in weight from 3 cwt. to 45 cwt., and are generally struck by means of clock-work. In no case does the bell itself move, the clapper or clappers, alone being actuated by the machinery. It is well known that the sound of a bell is curiously fluctuating. In the open country or at sea, in the neighborhood of church bells, the sound may be heard rising and falling, the peal swelling out as if close at hand—now fading into the thinnest sound, as if retreating far, far away. These effects are familiar to most people, and in themselves are really beautiful; but they come into play injuriously when the sound is wanted to be evenly distributed over a certain area. The truth probably is, that the vibrations from the largest bell are not of sufficient intensity to yield a sound capable of overcoming opposing influences, even of a slight nature. The sound produced in the immediate vicinity of the bell seems, no doubt, exceedingly powerful, the greatest energy of vibration being there exerted; but, at moderately long distances, this apparent energy is dissipated, and the bell ceases to be of use. It will be easily understood that little dependence can be placed upon bells as trustworthy sound signals for long distances. The effective sound range of the largest bell is at all times very doubtful; the wind may carry it to a distance even of 10 or 12 miles, but against the wind it may be inaudible at less than a quarter of a mile.

In one form the bell continues to be serviceably employed, viz., when fixed on the top of a large buoy, with four hanging clappers around the outside of the bell, which alternately strike the bell as the buoy is moved from side to side by the action of the waves. An incessant tolling is thus kept up; and at night, or in foggy weather, the signal is most useful to mark the turning points at the entrances to important ports, and at other places where the navigation is intricate, or to mark isolated dangers. The number of bell buoys round the British coast is considerable.

Gongs.—The next kind of sound producer we have to notice is the gong. To most of us, probably, the gong has an inviting sound, that is, as used for signaling purposes in our households. This instrument has been appropriated

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for use on board the light vessels round the coasts, owing, probably, to its peculiar, distinctive sound. The gongs used in the Trinity House service are about two feet in diameter, of Chinese make, and cost about £4 each. They are struck with a stick with a padded head, the strokes being very short, and delivered in quick succession, so as to bring up the gong into a vigorous state of vibration. The sound is undoubtedly distinctive, and serviceable at very short distances; but, like the sound of a bell, is soon dissipated after leaving the immediate vicinity of the instrument. Passing vessels may approach nearer to a lightship than to a rocky coast marked by a lighthouse; therefore, a sound with only a short range may oftentimes be of great service. In many lightships, however, the gong as a fog-signal is now superseded by instruments of very much greater power.

Guns and Explosive Signals.—Guns are used for various purposes in connection with signaling. "The minute gun at sea," indicates that some vessel is in distress, and that assistance is required. This is one of the authorized distress signals. On board H.M. ships, guns have been employed for signaling in foggy weather, in accordance with an arranged code; and for salutes and other announcements, they are used at military depots and elsewhere. But their chief service has been as warning signals on headlands and dangerous points on a coast, to assist the mariner in foggy weather. The necessity for distinctiveness in the use of sound signals, and the loudness of the report yielded by the discharge of cannon, led to the adoption of this form of sound producer.

There is no doubt that these gun signals have been of the greatest value. Many and many a time the warning gun has been heard by the bewildered seaman in time to enable him to alter his course, and probably save his vessel. Formerly the guns were fired every fifteen minutes, but recently the interval has been altered to ten minutes. It would be difficult for two men to clean, load, and fire, for a lengthened period—say even twelve hours—with less intervals than ten minutes between each discharge.

The piece of ordnance ordinarily employed was the old long 18-pounder, with a 3-lb. charge of powder: but in the Trinity House experiments at the South Foreland, it was found that a short gun, the 24-lb. howitzer, gave a better sound than the long 18-pounder. Professor Tyndall thus sums up his opinion of the gun as a fog signal:

"The duration of the sound is so short, that, unless the observer is prepared beforehand, the sound, through lack of attention, rather than through its own powerlessness, is liable to be unheard. Its liability to be quenched by a local sound is so great, that it is sometimes obliterated by a puff of wind taking possession of the ears at the time of its arrival. Its liability to be quenched by an opposing wind, so as to be practically useless at a very short distance to windward, is very remarkable."

Professor Tyndall continues: "Still, notwithstanding these drawbacks, I think the gun is entitled to rank as a first-class signal."

In 1874–76, some experiments were made at Woolwich Arsenal, with the view of reducing the labor of firing, so as to enable two men to fire at more frequent intervals, and also to produce, if possible, a more effective report than had been obtained by discharges from guns of ordinary pattern. Colonel Eardley Maitland, of the Royal Gun Factories, Woolwich Arsenal, devised a form of gun, breech-loading, with six chambers, similar, in some respects, to a revolver, and with a parabolic mouthpiece fitted to the muzzle. The experiments gave promise that this fog signal gun would prove a success, and ultimately it was conveyed to the North Stack, near Holyhead, in order that it might have a practical trial. To reach the station, it was necessary to cross very bad mountain roads, and the gun received a severe jolting, and probably jarring, for it broke down shortly after being used. No further attempt was subsequently made to repair the damaged gun, nor to manufacture another, owing to the attention of the Trinity House being then diverted to gun cotton as an explosive sound producer. It should also be mentioned that, in the trials at Woolwich, one experiment was devoted to testing the comparative advantages of the various

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kinds of service powder for noise-making purposes. The powders tested were: 1. F. G. (fine grain). 2. L. G. (large grain). 3. R. L. G. (rifle large grain). 4. P. (pebble). In point of effectiveness in sound producing, the result of the trial placed the powders exactly in the order in which I named them; the fine grain, or most rapidly burning powder, giving indisputably the loudest sound; while the report of the slowly burning pebble powder was the weakest of all. The 80 and 100 ton guns, fired with charges of 300 and 400 lbs. of pebble powder, do not make anything like so terrible a noise as the enormous charge would lead one to expect. The sound seems to lack intensity; and, in comparison with the sharp smack of the detonation of gun cotton, or of a much smaller charge of more rapidly burning powder, appears to be more of a prolonged and somewhat soft roar.

While upon the subject of guns, I must not omit to refer to the very ingenious invention of the gas gun by Mr. J. R. Wigham, of Dublin, the advantages claimed for which are that, where a supply of gas is available, the apparatus is very easily applied, and that, the gun can be loaded and fired at a considerable distance from the point of explosion. The gun consists merely of a tube about 18 inches bore and 12 feet long, placed at the point where the signal is required to be made, and connected with a gas main or gas holder, by iron piping. The gun is loaded with an explosive mixture of gas and atmospheric air, by turning on a cock simply, and is fired by a light applied by percussion or otherwise to the shore end of the tube, the explosion taking place at the mouth of the gun almost immediately. Mr. Wigham states that a gas gun may be fixed at the water's edge, or on a rock in the sea, at half a mile from the loading and firing station. The idea, which is certainly one of originality, was conceived by Mr. Wigham when he was engaged in connection with the application of gas to the lighthouse at Howth Bailey, and his experiments at that station have met with a very encouraging amount of success, but the system is not yet in practical operation as a fog signal.

In 1874, the Trinity House obtained the consent of the War Department to some experiments being made at the Royal Arsenal, with the object of ascertaining the value of the sound produced by the explosion of varying quantities of gun cotton. The explosion of gun cotton takes place so instantaneously, that an exceedingly sudden and sharp blow is given to the surrounding air, whereby a sound wave of great initial intensity is generated. A number of comparative trials were made at Woolwich and elsewhere, in which the superiority of gun cotton over gunpowder was incontestably demonstrated. It was found that charges of gun cotton, however fired, yielded reports louder at all ranges than equal charges of gunpowder; and further experiments proved that the detonation of half a pound of gun cotton gave a result at least equal to that produced by the firing of a 3-lb. charge of gunpowder. During these experiments, the various charges of gun cotton had been merely suspended from a horizontal bar, or in the focus of a large parabolic reflector, and fired by means of electricity. To explode gun cotton, it is necessary to employ a detonator, consisting of a small cylindrical copper case, resembling an elongated percussion cap, containing a certain quantity of fulminate of mercury. This detonator is inserted in the heart of the portion of gun cotton to be exploded, and an attachment is then made with one wire, connected with a small electric machine, and with another attached to a conducting plate embedded in the earth. On turning the handle of the machine, a current is induced sufficiently strong to generate a spark at the connection of the wires with the detonator, which, coming in contact with the fulminate of mercury, immediately explodes it, and instantaneously the explosion is communicated to the gun cotton. If gun cotton in a wet state is used, it is necessary to have a small plug or primer of gun cotton, into which the detonator is inserted. Four processes then take place, viz: 1. Generation of electric spark. 2. Ignition of detonator. 3. Communication of explosion to dry primer. 4. Communication of explosion of dry primer to the wet portion. The entire operation is, however, perceptible to the human sense as one explosion only. It will be readily un-

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derstood that to discharge gun cotton in this way entailed some little expenditure of time and trouble, and might prove inconvenient, if required to be repeated every ten minutes for many hours during fog.

But it being clearly demonstrated that the explosion of gun cotton gave a very effective sound, a project emanated from the Deputy Master of the Trinity House (Admiral Sir Richard Collinson, K. C. B.), for making a rocket serviceable for carrying a charge of gun cotton up to a certain height, and then causing it to explode. This project was, with the aid of Mr. Brock, the well-known pyrotechnist, and, subsequently, Mr. Mackie, and the officers of the Woolwich Arsenal, after numerous experiments, made a practical success; and now, at five stations on our coasts, we have sound rockets, either substituted for guns previously used, or established *de novo* for signaling in foggy weather.

The following description of the rocket now used is given in the instructions issued to the fog-signal attendants at Flamborough-head, where sound rockets have been in use since January, 1878. The explosive used is a slight modification of gun cotton, called tonite, which is said to be cheaper than ordinary gun cotton, and as effective for producing a loud report.

DESCRIPTION OF ROCKETS.

For purposes of safety, the rocket is supplied, and is to be kept, in three parts, viz.:

(1.) *The Rocket.*—This is a case charged with the ordinary rocket composition, and is intended merely to carry up the explosive charge to the required height, and then to ignite the detonator which is to explode the tonite.

(2.) *The Detonator.*—This is an enlarged percussion-cap, filled with fulminate. Its duty is to cause an explosion to take place in the heart of the tonite charge, whereby that charge is exploded. The detonator is ignited by the burning of the rocket composition.

(3.) *The Tonite Cartridge.*—This is the explosive which produces the report, and which, with the detonator placed inside it, is to be fitted in the head of the rocket, when immediately required for use.

The fitting together of the three parts can be accomplished in less than a minute; the rocket is then lighted by applying an ordinary fusee to a piece of Bickford fuse, communicating with the rocket composition. The whole operation occupies less than two minutes. The cost of the rocket is about 1*s.* 5*d.*, whereas each discharge of the gun costs 2*s.*; and in foggy weather a rocket is sent up every ten minutes. The advantages gained by the introduction of the sound rocket are indisputable, in one particular more especially.

It frequently happens that the sound of a signal intended to be spread over an arc of, say, 180 degrees to seaward, is obstructed, or deflected, by intervening obstacles, so as to cause uncertain parts of the arc to be immersed in sound shadow, into which the sound penetrates with very feeble effect, and often not at all. This difficulty the rocket has surmounted most successfully.

The explosive charge is carried up to the height of about 600 feet, and is there caused to explode in free air. From the height at which the explosion takes place, the direct sound is sent downwards into places which would be completely hidden from the level at which a gun could be fired, and which would seldom be reached by the sound of its discharge. At Flamborough Head, the gun was placed on the extreme edge of the point, the cliffs being about 100 feet high. But in Bridlington Bay, at a very short distance to the south-westward, the gun was invisible at the sea level, on account of intervening faces and edges of the cliffs. A practical trial of the rocket *versus* the gun at this station clearly showed the value of the former. One man walked along the edge of the cliff, keeping the gun in sight, and several observers were below on the rocks at the foot of the cliff, it being low water at the time. It had been arranged that, upon intimation from the observers below, the man above should signal to the people at the gun station to fire, first a rocket, then a gun. At a quarter of a mile from the point, with a light wind against the sound, the first experiment was made. The rocket gave a loud and sharp report, the gun a dull, heavy thud. At half a mile the rocket was very loud, the gun very faint. At 1½

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mile the rocket was loud and distinct, the gun heard only by two observers, and then only with the most strained attention. The fact of the explosion of the rocket having been visible and audible on each occasion, shows that it was clear of the obstructions which quenched the sound of the gun, and hid its discharge from sight. It should also be mentioned that the charge of the gun is 3 lbs. of powder, and that the explosive charge of the rocket consisted of 4 oz. of cotton powder.

The sound rocket is now in use at Flamborough Head, at Lundy Island, the Smalls Rock, in St. George's Channel, at Heligoland, and at the Tuskar Rock, on the south-east coast of Ireland. The system offers the means of placing an effective fog signal at a rock lighthouse station, where limited space and accommodation would prevent the establishment of a gun, or signal requiring furnace and machinery.

The development of explosive coast fog signals has not gone beyond this point. Gun cotton and cotton powder (or tonite) may be handled and stored with quite as much safety as gunpowder; in fact, they are really less dangerous; but it has not yet been shown that other explosive compounds, such as dynamite, lithofracteur, blasting gelatine, or any other nitro-glycerine mixture, can be made practically serviceable. Some freeze at a temperature a little above 40° Fahr., and others do not lend themselves to manipulation, and to safe storing for lengthened periods. There is, however, every probability that further advances will be made.

One other form in which explosive signals are now used may here be mentioned. I have alluded to the gun fired at intervals of about a minute being the authorized signal of distress for ships at sea. Mr. Gardiner, of the Cotton Powder Company, has sent me particulars of a kind of signal which may be fired more easily, expeditiously, and effectively than the gun, thereby obviating loading every minute, an important consideration with a vessel in distress. This consists in a small charge of tonite made up in a sort of cartridge. When required to be used, one of these cartridges is dropped into a socket, and by pulling a lanyard attached to a friction tube, a small quantity of powder at the base of the signal is ignited, which blows the charge up into the air about 600 feet, where it explodes. At the moment of explosion some brilliant stars are also shot out, and thus the signal represents either a gun or a rocket, both distress signals. I am informed that many vessels have been supplied with these rocket signals, that their effectiveness is undoubted, and that the Board of Trade have sanctioned their use in lieu of either guns or rockets.

One further application of explosives requires attention, one probably more familiar than agreeable to most of us. I allude to the use of exploding signals on railway lines, to convey signals to engine-drivers and guards in foggy weather. and to do duty for the semaphores and colored light signals when they are obscured. The system appears to be, that a signalman, furnished with a supply of detonators, places himself near to the signal-box or semaphore in connection with which he works, and uses the detonators to stop a train, if the line is blocked by the fixed signal. The detonator consists of a small quantity of coarse gunpowder, tightly bound up with three percussion caps; it is fixed on the rail with lead clamps, and is exploded by the wheel of the engine going over it. The system is said to be fairly effective; but it is probable that the British public generally would not indorse that opinion, for most people are fully aware of the annoying delays involved by the system, and certainly do not relish the sudden explosions to which they are treated, while chafing under enforced detention in the train. There seems to be plenty of room for improvement: the system is cumbrous, and admittedly expensive; and we may well hope that a more effective and less objectionable method of signaling in fog may be devised for our railways.

Whistles.—The next instrument which claims our notice is the whistle. We will first regard it in connection with coast fog signals. For this purpose, whistles, whether operated by steam or compressed air, do not appear to have found so much favor in this country as in the United States and Canada; indeed, with the exception of one station in the Clyde, where two small whistles, sounding dif-

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ferent notes, are in operation, there are no fog-signal whistles on our coasts. In the United States they have been employed at various points since the year 1851. The first was set up by Mr. C. L. Daboll, at Beaver Tail Point. In Canada, also, whistles have been in use for some time, the type adopted being that invented by Mr. Robert Foulis, of St. John's N. B., and known as the Vernon-Smith whistle; and in this country Mr. W. H. Bailey, of Salford, Manchester, has given much attention to the manufacture of whistles suitable for sound signaling. Steam whistles are simple enough in their arrangements, requiring only a boiler for generating steam, and a simple mechanical arrangement for opening a valve for the periodic passage of the steam to sound the whistle.

For air whistles, it is necessary to have some motive power to compress air, and also some mechanical arrangement to regulate the admission of the compressed air to sound the whistle.

In the Trinity House experiments of 1873–4, it was shown that the sound of the most powerful whistles, whether blown with steam or air, was generally inferior to the sound yielded by other instruments, and, consequently, no steps have been taken to extend their use in this country. Various reports have been circulated as to the great distance at which whistles have been heard on the American and Canadian coasts, but no such results as those claimed were obtained in the very careful trials, made with both American and Canadian whistles, at the South Foreland, in 1873.

The sounding of a whistle is caused by the vibration of the column of air contained within the bell or dome, the vibration being set up by the impact of a current of steam, or air, at a high pressure. It is probable that the metal of the bell is likewise set in vibration, and gives to the sound its *timbre*, or quality. It is to be noted that the energy so excited expends its chief force in the immediate vicinity of its source, and may be, therefore, regarded as to some extent wasted. The sound of the whistle, moreover, is diffused equally on all sides. These characteristics, to some extent, explain the impotency of the sound to penetrate to great distances. Difference in pitch is obtained by altering the distance between the steam orifice and rim of the dome; when brought close to each other—say within half an inch—the sound produced is very shrill, but it becomes deeper as the space between the rim and the steam or air orifice is increased.

The most recent adaptation of the whistle, as a fog signal, is shown in an automatic signal buoy, devised by Mr. J. M. Courtenay, of New York, by which a powerful whistle, fixed at the top of a buoy, is sounded automatically by the action of the sea. The apparatus consists of a buoy, 12 feet in diameter, with a tube 33 inches in diameter, and 32 feet in length, passing vertically through the center, and descending below the bottom of the buoy to a depth of about 20 feet, the object of this length of tube being to reach a depth where the water is not subject to wave agitation. The bottom of the tube is open, and freely admits a column of water, which is maintained at a constant level, and is not affected by the external superficial wave motion. The buoy, however, to which the tube is fixed, moves with the surface undulations of the water, and, of course, carries the tube up and down with it, thus establishing a piston and cylinder movement, the column of water in the tube forming a piston, and the tube itself being a moving cylinder, the weight of the buoy and the tube exercising a considerable pressure. By means of the motive power so established, air, which is admitted by stop valves into that part of the tube which is above the level of the water, is compressed and forced through a pipe 2½ inches in diameter, communicating with and sounding the whistle at the top.

One of these buoys has been practically tried off the Goodwin Sands for some months, and has proved a success; two more are about to be placed at other points. On the coasts of the United States, France, and Germany, they have also been in successful operation for several months.

Whistles are supposed to be the best medium for making signals by sound on board steamships. The regulations, which I have previously quoted, specify the whistle for steamers; but it is necessary that precaution should be taken to en-

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sure the whistles giving effective sounds. Many that I listened to appear to me to be dismal failures, more especially when first sounded, for frequently the condensed steam causes so much water in the pipe, that when a sound signal is required to be made in a hurry, only a rush of water comes through, without any effective sound.

On board the *Duke of Leinster* steamship, running between Glasgow and Dublin, a novel form of whistle, consisting of an organ pipe fitted on to the steam pipe, is said to give very superior results. It is said that it does not get choked like ordinary whistles; and that the sound emitted is loud and resonant, without the shrill disquieting tone of many whistles. This instrument is patented by Messrs. Hannan & Buchanan, of Glasgow.

With regard to the use of whistles on locomotive engines, I have endeavored to ascertain from sundry gentlemen connected with railway engineering (to whom I beg to offer my best thanks for their courtesy in replying to my inquiries), whether this kind of signal is the best for the purposes required, and from the replies I gather that the feeling is, "Well, it might be better, but it just answers." It does not appear that much is known by railway engineers about the construction or shape of whistles, and they seem to share the popular notion that the shriller the sound the more effective it is. Perhaps I may here venture, in the general interests of the traveling public, to utter a protest against the inconsiderate and often unnecessary manner in which whistles are sounded in the great railway stations of this country, and London in particular. I think it probable that this meeting will sympathize with me when I say that, in these days of nervous susceptibility, and when so many thousands of people travel daily by rail, something ought to be done by the railway authorities to abate the nuisance of unnecessary whistling, and certainly to put down the sudden, shrill, ear-piercing screeches, which make a strong man's nervous system tingle again, and which echo from roof, wall, and ground in reverberating shrieks. There is enough hubbub and racket at all stations, caused by the bustle of travelers, the arrival and departure of trains, the shouting and banging of doors by porters; and though all this may be called exhilirating, yet the addition of whistle screeches is too much to impose upon an enduring public. Drivers and stokers, with their deadened perceptions, are probably not aware of the real pain they often inflict on many persons by their thoughtless use of the whistle. If sound signals are so necessary, let them be low, soft sounds, or a full-toned bell. Such as are used on locomotives in the United States would be a great relief.

Fog Horns.—The next class of instruments to which reference should be made is the horn, or trumpet, in which air or steam pressure is employed to set in vibration a metallic reed or tongue, which vibration is communicated to air inside the trumpet, and also to the molecules of the metal of which the trumpet, or horn, is formed.

Mr. C. L. Daboll, of the United States, to whom reference has been previously made, introduced, in 1851, an instrument of this kind to the notice of the United States' Lighthouse Board, and a trial was made at Beaver Tail Point, Rhode Island. This instrument was sounded with air condensed by two air pumps, worked by a horse, the compressed air being stored in a receiver, and the trumpet sounded at a pressure of about 40 lbs. to the square inch. Ultimately, Mr. Daboll employed Ericcson's caloric engine as the motive power for condensing the air, and an automatic arrangement for regulating the blasts, and in 1862, he introduced his improved signal to the notice of the Trinity House Corporation, who gave it a practical trial at Dungeness. The results being very satisfactory, the Corporation placed other instruments of the same kind at several places round the coast, and one was fitted up on board the Newark light-ship. The experiments at South Foreland showed such instruments to be, under some conditions, very efficient, but they suffered from several disadvantages, which have led probably to their disuse of late years. I have alluded to the fact of some of the initial power being wasted in the case of whistles, by the metal of the dome, or bell, being set in vibration; this occurs to a greater extent with the huge brass trumpets which have generally been associated with reeds. In a paper read

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before the Royal United Service Institution, in May, 1875, Admiral Sir Richard Collinson, in speaking of these horns, says, that "there are objections to the trumpet being made of brass, and also to the necessity which exists for tuning the reed in unison with the fundamental note of the trumpet." Sir Richard goes on to remark, "the use of a trumpet consists chiefly in concentrating the sound into a beam, and thus causing it to be projected through the air with greater force in any required direction. The brass trumpet, no doubt, does this to a certain extent; but as the molecules of the metal are also set in vibration, sound waves appear to be generated from all parts of the external surface of the trumpet, so that, although a very loud sound may be produced in the immediate neighborhood of the instrument, it is open to doubt whether that sound is transmitted with force to any great distance, its strength being, so to speak, dissipated in the space close to its source." The local noise occasioned by the vibration of the trumpet would be intolerable for any length of time. At the present time there are very few reed instruments with brass trumpets in operation, many of those originally established having been superseded by the siren, an instrument of which I shall speak presently. In connection with the development of reed horns very much is due to Professor F. H. Holmes, whose energy in connection with the electric light is well known. Under his immediate superintendence and advice two reed horns, sounded directly by steam, were fitted on board two light vessels sent out to China, and have worked very satisfactorily.

Reed horns are also used on board ship, chiefly sailing vessels, in compliance with the compulsory fog signals, and the optional sound signals, in connection with the "rule of the road" at sea. The horns now exhibited are lent for this evening by Mr. Nathaniel J. Holmes, of Holmes' Marine Life Protection Association (Limited). They are said to be very effective, but in a seaway, with the vessel rolling heavily, the seaman has some difficulty in working the instruments. It is air pressure which sets this reed in vibration, and produces the sound. In some trials recently made by the German Admiralty, these horns held a commanding position.

Recently, there has been brought into this country, from the United States, an apparatus known as Barker's marine safety signal, intended for use on board ship, to make sound signals. The apparatus has many merits, one of which is its simplicity in working; the second is that every signal is sounded automatically when once set; and a third is that, with the horn attached, it gives a very good sound. Compressed air is employed at a pressure of 6 lbs. to the square inch, and the sounding principle is a reed for the horn; but the inventor says, it can be equally well connected with the steamer's own whistle. The main object of the inventor appears to be to bring into use a short code of compass signals, by means of which vessels can indicate to one another their respective courses, the signal system consisting of eight combinations of long and short sounds. But it may be observed that the adoption of his code would make it necessary for the law to be altered, there being no permission or obligation to employ such signals in the rules now in force. And, again, the principle of long and short sounds which has been adopted, does not commend itself for service at a moment when there is no time to lose in deciphering the meaning of a sound signal from an approaching vessel. Captain Barker, however, has evidently had these considerations in his mind, for, in his descriptive pamphlet, he remarks that, though numbers of practical seamen consider the suggested code to be the simplest and best as yet brought forward, its adoption is by no means a *sine qua non*, since the machine can, with equal facility, blow any code which may be decided on. Captain Barker would probably do well to adapt his machine to sound only those signals provided for in the regulations.

Sirens.—We now come to the instrument which has been authoritatively described as "beyond question the most powerful fog signal which has hitherto been tried in England." In 1872, a committee from the Trinity House, who went to the United States, witnessed the performance of an apparatus known as the siren, and patented by Messrs. Brown, of Progress Works, New York, and in

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the experiments at the South Foreland one of these instruments was sent over to be tried.

The instrument sent from America could be sounded either with steam or compressed air, made to pass through a fixed flat disc, fitted into the throat of a long trumpet, connected with the steam or air pipe. This disc has twelve radial slits, and behind it is a rotating disc, with twelve similar slits, the rotation being effected by separate mechanism. Imagine, then, the pressure of steam or air to be on, with one disc fixed, and the other rotating; it will be understood that the slits in each frequently coincide—in fact the twelve silts in one revolution coincide twelve times, and at each coincidence a puff of steam or air, at great pressure, escapes through into the trumpet. It is the rapid succession of these puffs which form the sound of the siren. The disc is rotated so as to make 2,400 rotations in a minute; and as there are twelve coincidences in a revolution, it follows that the number of puffs passing through in a minute would be $2,400 \times 12 = 28,800$.

It can readily be understood that a sound of surpassing power is thus generated, and as the vibrations produced are not taken up by the cast-iron trumpet, the sound issues from the mouth in a condensed beam of great intensity.

It is not of importance to record the longest distances at which the siren has been heard, the sound-range under different atmospherical conditions being so exceedingly variable; but in regard to its superiority over other instruments, we may say that, under meteorological conditions unfavorable to the transmission of sound, the voice of the siren had a greater range than that of any other sound-producer; and that, when local noises—such as those of wind in the ears, rattling of rigging, breaking waves, shore surf, paddle-wheels, and the working of engines—have to be contended with, "its density, quality, pitch, and penetration, render it dominant over such noises after all other signal soudns have succumbed." It is obvious that this power to overcome obstructions is the true test of the value of a sound signal, and it is not surprising that the experience of the siren at the South Foreland should have led to the extensive adoption of this form of fog signal on the coast of Great Britian. Since 1874, no less than 22 sirens have been placed at the most salient lighthouse stations on our coast, and 16 on board lightships, moored in positions where a guiding signal is of the greatest service to the passing navigation. It should be added that, in the experiments, steam alone was used for sounding the siren; but the instruments now in operation on our coasts are sounded with compressed air, the motive power being caloric engines of greatly improved design and construction, examples of which are in exclusive use at the Lizard, both for the electric lights and the fog signal. Steam is not available at many lighthouse stations, owing to a scarcity of fresh water; and the caloric engine, which also rotates the siren disc, is regarded as safer and more economical in working than a high pressure steam boiler, and is independent of water supply. In America, Canada, and some other countries, steam has been employed with considerable success.

At Howth Bailey, a gas-engine is employed as a motor for compressing air for the siren now in operation there. This arrangement is due to Mr. J. Wigham, of Dublin, and is said to work very efficiently.

Messrs. Stevenson, of Edinburgh, have proposed that the Perkins engine should be employed as the motor for siren signals, but I am not aware that this suggestion has yet been carried out.

The adoption of the Siren as the most efficient sound signal for use in foggy weather, may be regarded as an important epoch in the history of the development of the use of such signals. Improvements have been made by Mr. James N. Douglass, engineer to the Trinity House; and Mr. Slight, Superintendent of the Trinity House work-shops, has invented an improved arrangement by which, instead of flat discs being used, the siren consists of two concentric cylinders, with slits in both, one inside the other, the outer one being fixed, and the inner one revolving, with the smallest possible clearance between them. The advantages of this arrangement are, that the suddenness of letting on or taking off the pressure is much increased, whereby the successive blows upon the air are rendered much sharper, and the sound intensity augmented. It is also

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considered an improvement mechanically, by somewhat lessening the friction. Professor F. H. Holmes has succeeded in rendering the rotation of this siren cylinder automatic, with perfect control of the speed and consequent pitch, and an apparatus of this kind has not long since been fitted on board the light-ship at the Seven-stones.

It seems probable that before long the siren will be brought into more general use for maritime purposes. Already it has been introduced into the Royal Navy, for which service Professor Holmes has supplied three small-sized instruments. Messrs. Sautter, Lemonnier & Co., of Paris, have also produced a steam siren, which they claim can be used not only as a fog signal at lighthouse stations, but also for ships, and, in a smaller form, for locomotives, in the place of the whistle. Mr. Wigham, of Dublin, has also designed a form of siren for steamships, driven by a small turbine, actuated by the current of steam or air by which the instrument is sounded, the rate of rotation being controlled and rendered uniform by a simple governor.

Messrs. Sautter, Lemonnier & Co. have more recently introduced a double siren, in which two sirens, having different numbers of orifices in their respective cylinders, produce simultaneously two notes in the trumpet, and by this means the power of the instrument is more than doubled, and a characteristic feature is given to the sound.

It now remains to offer a few general remarks upon the subject.

It is obvious that, with the increasing use of sound signals, there is an increasing necessity for differentiating them. Something must be done to prevent one from being mistaken for the other: in fact, it is necessary that every signal should have its own characteristic. This essential element, as regards coast fog signals, has by no means been overlooked, and as each lighthouse is made to proclaim its own individuality, so every fog signal, established on our coast has been made to particularly indicate itself by some distinguishing feature. One great reason why explosive reports, whether from guns or rockets, are made use of, is because their sound is so entirely different from that of the blast of a siren, a reed horn, or a whistle. Indeed, the three latter strongly resemble each other, and can only be distinguished by trained ears. It has also been found useless to attempt to get differential signals by means of pitch of the note alone. To employ a high note at one station, and a low note at another, would, in the present condition of the musical cultivation of mariners, generally, be more likely to lead to confusion and disaster; although, as Sir Richard Collinson observed, in 1875, it might be possible to obtain an effective distinction by sounding a high and a low note in direct contrast. It has been frequently proposed to introduce long and short blasts; but here, again, experience has shown that many difficulties and risks would attend such an arrangement, and might result in conveying wrong information to the mariner, and lead him into danger. For real practical utility it has been found that, for the present, it is best to trust to the distinctions which may be obtained by varying the number of blasts, and the length of the silent interval. This is a system which is intelligible to the most ordinary understanding; and, accordingly, it is on this basis that the characteristics of sound signals are founded. By making the blasts to occur in groups, and varying the length of the intervals between the groups, on the same principle as that now applied to the new class of group-flashing lights, sixteen fundamental distinctions may readily be obtained, thus—commencing with an interval of half a minute:

1 blast	every	½	min.	3 blasts	every	½	min
"	"	1	"	"	"	1	"
"	"	2	"	"	"	2	"
"	"	3	"	"	"	3	"
2 blasts	"	½	"	4 blasts	"	½	"
"	"	1	"	"	"	1	"
"	"	2	"	"	"	2	"
"	"	3	"	"	"	3	"

The introduction of compulsory and optional sound signals in the new regulations for preventing collisions at sea, has naturally much extended the use of sound signals on board ship, and there can be no doubt that such signals should be entirely different from those made at fixed fog signal stations. It is said that already some difficulty has arisen in reference to the clause in the regulations, which enacts that in foggy weather a steamer shall sound a prolonged blast at intervals of not less than two minutes,

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the fact being that several coast fog sirens sound the blast every two minutes. Unless checked, this, perhaps, is a danger likely to go on increasing as ships' sound signals become more powerful and more generally used.

One point occurs to me, in connection with those gentlemen who give much time, and trouble, and, probably, spend much money, in developing sound signals. I observe that they all take up some special code of signals, and then show how well their instrument is adapted for it. Now, if I might give a piece of advice to those gentlemen it would be, first look at the law, and see what signals are provided, then adapt your apparatus, whatever it may be, to making those signals. Don't require the law to be altered to suit your instrument—that is putting a real difficulty in the way; but make your instrument suit the law as it now exists.

I may remark it is not easy to see how the system of long and short sounds can at present be brought into satisfactory operation. Such distinctions are extremely pretty and simple upon paper, but they assume a vastly different aspect in the mind of an anxious and, perhaps, not over intelligent master mariner, on board his vessel, say in the Downs, in a thick fog. All around he hears horns and whistles blowing, and all he attempts to do is to keep clear of those vessels which, by the sounds, appear to be nearest. Of what use, then, would be the combinations of long and short sounds? Would he, in his bewildered state, care to try to distinguish between them? I venture to say he would have neither the time nor the inclination to do so; and it must not be forgotten that, in making provisions of this kind, it is not the skilled, clear-headed, highly-educated, Royal Naval or merchant captain you have to consider, so much as the thousands of experienced, weather-beaten master mariners, who know well how to navigate their vessels under trying circumstances, but whose minds are not adapted for comprehending any system requiring accurate and attentive observation, to which is tacked on the necessity of finding out the meaning after the observation is made.

As regards the present development of our coast fog signals, there is every reason for congratulation. This new branch of coast marking has been brought up to a very effective condition; no efforts have been spared to cope with the seaman's greatest enemy, fog, and the remarks which I have had the honor to address to you indicate with what success these efforts have been attended. By the aid of sound signals, the mariner is now enabled to continue his voyage with comparative safety, even when his vessel is enshrouded with a thick pall impenetrable by the keenest vision; and there is little doubt that those who have their business in the great waters are ready gratefully to acknowledge the humane spirit which has prompted the development of these signals, as well as the practical benefit which they derive from them.

ON THE ALTERATION IN THE DENSITY OF STEEL THROUGH HARDENING AND TEMPERING.

By C. FROMME.

From "Abstracts" of the Institution of Civil Engineers.

THE experiments were made first on four bars of the same dimensions, 100 millimeters (3.9 inches) long, and 7 milimeters (0.27 inch) on the side, and then on bars of the same length but of different sections. The results obtained are as follow :—

After hardening in cold water the density decreases, or in other words the volume increases; the thicker the bar the less the increase.

After tempering the volume again diminishes, the increase being at "straw" reduced to one-half, and at "blue" to about one-fifth of the total increase gained after hardening, returning at "gray" to the original volume when soft. The molecular condition must, however, be

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different, as the steel retains twice as much permanent magnetism in the "grey" temper as in the soft. If the bar is heated to a bright red and cooled slowly, the volume is larger than in the original state before hardening, the difference being about one-sixth the total increase gained after hardening. The question as to whether the density varies from the exterior to the interior of the bar, the Author proceeded to determine by eating off successive layers by acid, and determining the specific gravity of the remainder; but as a fissure was ultimately discovered inside the bar, the results must be considered untrustworthy. Further experiments in this direction are certainly desirable.—*Annalen der Physik und Chemie.*

A GRAPHIC METHOD FOR MEASURING CROSS-SECTIONS OF EARTHWORK.

Par M. H. WILLOTTE.

Translated from Annales des Ponts et Chaussées.

The employment of graphical methods of solving problems tends to become more and more general. Every day methods are invented or improved, and the progress already made only calls more strongly for the attention of engineers to this subject.

We propose in this note to examine two problems, which are presented for solution whenever it is desired to estimate in an expeditious manner the area of a cross-section.

1st Problem. To construct the profile of a cross-section of earth work, and obtain its area, by a simple method.

Provide a series of sheets or cards representing the outline of the usual cut or embankment of a road or canal. These cards will bear certain lines and scales which result from what is to follow. Figure 1 shows, on a reduced scale, one of these sheets for the half profile of an embankment of a single track railroad.

What is required to complete the profile thus far exhibited? It is clear that nothing more is necessary than to draw the profile of the original surface. This may be done in a ready manner by the aid of a prepared scale, graduated to the scale of trigonometrical tangents, as shown in Table, Fig. 2.

This little instrument is then applied to the axis of the cross-section diagram at the cut or fill height, and inclined at the angle of the natural surface.

It only remains to follow with a pencil the edge of the protractor, in order to complete the half profile TNMP.

The length of the slope and the breadth of base are read at once from the inclined scale drawn on the prepared card.

It is required finally to determine the area TNMP. This is done in the following manner, which is only an application of a more general method for the measurement of areas.

If we consider some point A arbitrarily chosen on the movable scale, but having a position mathematically defined, it follows that for each position of A, a corresponding point on the engraved sheet may be determined.

We can, therefore, trace beforehand upon the prepared sheet a series of curves, giving the area of the half cross-sections for each position of the point A, and the problem is then solved by a simple reading.

For reasons, which will be immediately apparent, the point A is taken at A_1 the point of tangency of TN (original surface line), and the curve to which all the lines are tangent, which cut off areas equal to the area TNMP.

To determine the nature of this curve we seek for the position of the point of tangency A, under the above conditions. This point will be at the intersection of TN and another line T'N', drawn infinitely near it in such way that the areas PMNT and PMN'T' are equivalent.

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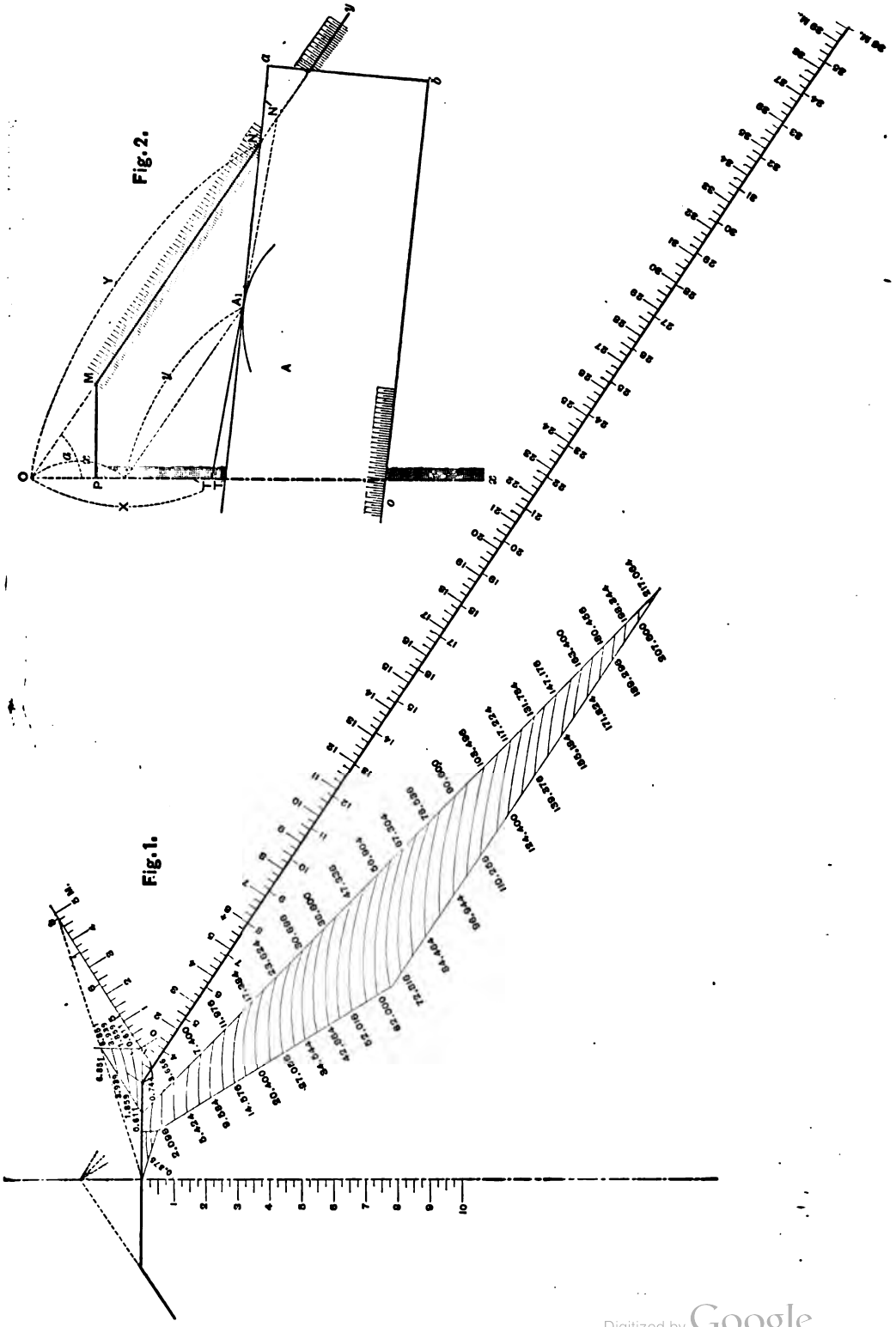

Fig. 2.

Fig. 1.

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The two infinitely small triangles TA_1T and NA_1N are equivalent. Hence the point A_1 is at the center of the line TN.

To determine the equation of the curve of the locus of A_1 under the prescribed conditions. Let Ox and Oy be co-ordinate axes, and let $OT=X$ and $ON=Y$. The area PMNT being constant, the area ONT is also constant (so long as the line NT does not intersect the line PM within the angle xoy, a condition which is taken into account further on).

Then we have

$$\text{area} \quad OTN=\frac{ON.OT.\sin\alpha}{2}=\frac{XY\sin\alpha}{2}$$

or $$XY=4K^2 \text{ a constant.}$$

As x and y are the co-ordinates of A_1 we have

$$x=\frac{X}{2} \text{ and } y=\frac{Y}{2}$$

and $$xy=\frac{XY}{4}=K^2..$$

The locus of A_1 is, therefore, a hyperbola having for asymptotes the axes Ox and Oy.

For different values of K^2 we may obtain a series of hyperbolas corresponding to different values of the half section PMNT. These curves may be termed *curves of equal areas.*

The advantages arising from the selection of the point A_1 under the assigned conditions, are obvious.

1st. The curves of equal surfaces being hyperbolas drawn relative to the same point O, and to the same asymptotes, are easily traced. Any one is easily constructed by means of some one of its tangents, and others of the series are readily derived from this.

The preparation of the table of areas is not all complicated. An area is calculated corresponding to one of the curves. Other areas are determined by the law of the dimensions of similar surfaces, and the numbers may be written upon the curves.

If the curves are traced in such a manner that they cut equal segments on one of the radii vectores from the point O, the *second differences* of these numbers are equal.

2nd. For each of the different methods of choosing the point, there is a graphic table of determinate form; and for each table there exists a system of equal surface curves generated by the different positions of A corresponding to equal areas. The curves are generally of a degree above the second, but as we have already seen they become hyperbolas of easy construction when we take for auxiliaries points analogous to A_1.

But the simplicity of construction is not the only advantage arising from this selection; for it is clear that it is an advantage to diminish as much as possible the length of the curves of equal surface; in taking A_1 the minimum of length is secured.

Fig. 1 represents cross sections, comprised between the following limits:

1st. Inclinations of surface varying from —0.33 to +0.33.

2d. Depths or *fillings* at the center, of 10 meters.

The prepared sheet would not be inconveniently large if both these limits were extended. A single sheet might serve for cross sections of different slopes.

The mode of proceeding to employ the system is as follows:

1st. Make a book of the cross sections, also a sufficient number of the proposed sheets to serve the purposes of the work in hand.

2d. Write within the profile of each cross section, the center cut or fill and the slope of the original surface (expressed as a ratio or tangent of the angle made with the horizon).

3d. Proceed to trace the lines TN by aid of the movable scale (the inclination being measured by aid of graduations on the lower edge as at O in fig. 2).

4th. Read the numbers upon the curves to which in each case the line falls tangent, and write these areas within the respective cross sections.

It may be remarked here that the tangency of the line TN is easy to determine, and moreover that an error of the first order, in determining the point of tangency, results in an error of the second order only in getting the areas.

5th. Complete the calculations indicated for estimating the volumes.

As the accuracy of the work depends so largely upon the accuracy of the prepared sheets, it will suggest itself that a shrinkage of the sheet would result in

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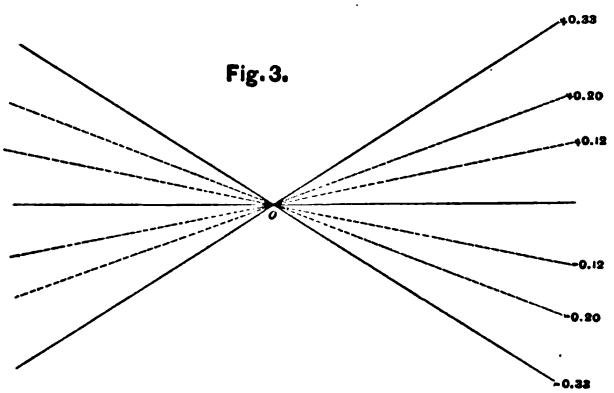
errors in the work. This does not necessarily follow except in cases obviously rare of unequal shrinkage in different directions.

In place of the movable scale for the measurement of inclinations, a common straight-edge ruler may be employed and the inclinations be obtained, by using the method of drawing parallels from a set of prepared lines like fig. 3, drawn to the different inclinations on each of the working sheets.

Fig. 3.

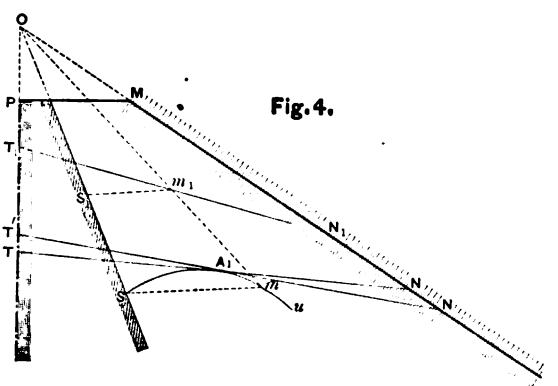


2d Problem. To determine with rapidity a large number of cross-section areas, by aid of graphic processes only.

This problem may be solved by aid of a diagram like fig. 4.

Draw the cross section P M N and construct very carefully the curve Su, the hyperbola whose tangents are TN and T′ N′ and also determine the area. (The position of the lines TN and T′N′ is determined without trouble, since OT $\times$ ON = OT′ $\times$ ON′ = a constant, and the curve Su can be traced accurately in a few minutes. The extreme points S and u are determined by the limits of the inclination of TN.) Draw also one of the radius vectors from O as OS and divide it into equal parts. Against each of the divisions write the area belonging to the curve passing through that point, if such curve were drawn according to the rule. The drawing is then complete.

Fig. 4.



Its use is explained as follows:

Let T_1N_1 be a line of original surface. It is required to determine the area of PMN_1T_1.

Through the middle point m_1 of this line draw Om_1 meeting the arc Su in m

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Join *ms* and then $m_1 s_1$ parallel to it. The number on the scale at S_1 is the area sought. This results from the property of the curves of equal surfaces described as above.

This process fails whenever the line T_1N_1 intersects the line PM within the angle TON. If many such cases occurred in any work a special construction easily devised might be prepared for them.

SANITARY SCIENCE IN ITS RELATION TO CIVIL ARCHITECTURE.

By E. C. ROBINS, F.S.A.

A Paper read before the Royal Institute of British Architects.

E. C. ROBINS, F. S. A., said he thought those architects who, for the last thirty years, had practically proved their interest in sanitary science in so far as it related to architecture could not be otherwise than be pleased with the obvious improvement in recent public opinion, and the quickening of the professional conscience thereon. Having referred to the works of pioneers in sanitary science, to the disgraceful condition of London before the Great Fire, to the suggestions of Patte for improving the state of Paris in 1797, and to the great impetus given to the consideration of sanitary questions in England by the visitations of cholera in 1842, 1847 and 1852, in which latter year his own attention was directed to the matter, he said he propcsed that evening to consider: (1). What had been defects in sanitary construction. (2). What were the remedies now generally available. (3). What further improvements were required. In London a system prevailed which compelled the professional architect to provide against the insanitary condition of the main sewers; he had to fortify the modern dwelling-house against sewer gas, which contaminated not only the air breathed by the inmates, but also the water they drank. It was not necessary to enter into much detail respecting sanitary defects. A summary was provided in a pamphlet entitled "Dangers to Health," written in a grimly-humorous way by Mr. Teale, surgeon to the Leeds Infirmary, and dedicated to his medical brethren. Such defects consisted not only in those things for which an architect might be blamed, but also in the faulty workmanship of artisans; in the jointing of bad iron and stoneware piping, in false levels and bad laying of drains, in perverse connections on the wrong side of traps, in ill-supported vertical soil-pipes, in the thousand evils emanating from the want of trained foremen and workmen. At the Conference on Public Health held in June last by the Society of Arts, Mr. Rawlinson had stated that house drainage was at the root of all sanitary reform, and that Earl Spencer's town house in St. James's place was the most perfectly drained house in London or elsewhere. The evidence given by Messrs. Eassie, Rogers, Field and Griffith, and other specialists before the Society of Arts, was referred to. The principles summarised by Mr. Griffith were quoted—principles which the author said were quite in harmony with many architects' previous practice. They were: (1). Communication between main sewer in street and house-drain should be disconnected or severed by an open-air space being left between house-drain and sewer. (2). The house-drain, air and water-tight, should be laid to such a fall as to be self-cleansing, free from deposit, and ventilated. (3). The soil pipe should be fixed inside the house and taken up full size above the roof. (4). The waste pipe should discharge into the open air instead of into soil pipes or a D trap. (5). There should be no means of drawing water from a cistern supplying a w. c., other than through the closet. (6). The waste pipes from sinks, baths, lavatories, &c., should be S trapped underneath, and made to discharge immediately into the open air, over trapped gullies. (7). There should be no connection with the main house drain, when laid underneath the house, except outside the main walls

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of the building. (8). "Pan closets" with D traps should never be used, nor should D traps be fixed under sinks, &c. The evidence of Messrs. Eassie and Rogers Field coincided in all material points with that of Mr. Griffith. The author prefaced the subject of warming and ventilation, the second division of his paper, by quoting a remark made to him by Professor Jenkin, to the effect that the study and control of the pressure of the atmosphere, and not the temperature, is the key to all sound ventilation. As that pressure was increased or diminished in its utilization, so ventilation was promoted or retarded. Following the suggestion of Dr. Parkes, it was desirable to restrict the thing known as ventilation "to the removal by a stream of pure air of the pulmonary and cutaneous exhalations of men, and of the products of the combustion of lights in ordinary dwellings, to which must be added in hospitals the additional effluvia which proceed from the persons and discharges of the sick." It was not only important that the air should be changed, but also that it should be drawn from a pure source and carried through clean channels. By the term "ventilation" the author meant a passage for the wind, change of air or atmospheric recuperation. A way in was wanted for the air and a way out for it in every building or portion of a building. Natural ventilation was the simple process of allowing the external atmosphere to mingle with the internal atmosphere of a building. Scientific ventilation was the same thing, but with this difference: in the former case the air was free to mingle or not as it pleased, and in doing so it created many inconveniences; in the latter, direction was given to currents of air produced by interchange, and a healthy commingling of the oxygen with the carbonic acid gases was secured without the dangerous and disagreeable accompaniment of draught. The business of ventilation was to direct the pressure of the currents of air admitted and required to overcome stagnation under conditions where no draught was admissible. The natural process by which the temperature of the air was raised was two-fold: by radiation and by conduction. Radiated heat he defined as possessing the peculiarity of passing directly through any intervening space, without parting sensibly with its heat, and warming the first obstacle to its passage, such as a wall or window, with which it came in contact; conducted heat was the warmth given off from any surface by direct contact with any substance whether air or otherwise. The conducted heat of an open fire passed into the air, escaping by the chimney flue, and was lost for heating purposes; the radiated heat of the open fire was alone available for raising the temperature of a room. Draught, however, was almost inseparable from the use of open fires, especially when they were placed directly opposite doors, whereby large quantities of air were drawn across the floor and passed up the chimney. With reference to the size and position of "inlets" in rooms, it was desirable to make the area of each opening not larger than from 50 to 60 square inches, and they should be placed on the same side of the room as the fireplace. The introduction of air by vertical shafts, suggested by a Mr. Whitehurst years before Mr. Tobin was heard or even thought of, was a sound principle, suited to the requirements of ordinary rooms which were heated by the open fireplace only. Mr. Robins then drew attention to several varieties of stove and grate, including those invented by Mr. Phipson, by Messrs. Verity, and other architects, and, amongst others, described the heating and ventilating processes adopted by the late Mr. T. H. Wyatt, in the new Hospital for Consumption at Brompton, and also in the Norfolk Hospital at Norwich, built by the same architect in conjunction with Mr. E. Boardman, of that city. Dr. R. E. Thompson had, in a letter to Mr. Robins, thus summarised his views: "I think that air should be admitted at the level of the various floors, and not from an underground chamber; also that the air so admitted should come from the east and west sides if practicable, and in any case should be passed over tubes of hot water. Air of uniform temperature is disagreeable and oppressive; it is better that the upper air should be colder than that of the floor, and that the warm air as it rises from the floor-level should be cooled and agitated as it mixes with the upper air by the incoming cool-

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er air. The foul air should be extracted by the open fire, and by the extracting flues at the top of the room, which should be heated by gas jets below, or made to communicate with a hot-air chamber above and in connection with turrets forming ventilating towers." With regard to w. c.'s, Dr. Thompson considered that the space they occupied should be heated to a higher temperature than the passages leading to them, and that a separate means of extraction should be adopted. In reference to systems of underground reservoirs or chambers for the accumulation of heated air to be transmitted through shafts to the different rooms of a building, everything depended on the cleanliness of those heated air-chambers. They were very difficult to keep clean, because they were out of sight, and were usually dirty and dusty; indeed, he had heard of some air-chambers in which decayed organic and vegetable matter had been allowed to accumulate; and of an instance in which a defective soil pipe had discharged into it part of its contents. Alluding to the various systems of heating, the author said that he had no great faith in any one of these, but that where he had to go beyond an open fire, in apartments too large for warming in that manner, he preferred hot water. Twice in his practice he had been obliged to substitute hot water for hot air, both instances being in churches. Two leading principles governed the supply of hot water for heating purposes, termed high pressure and low pressure. The latter provided for the supply of water at a low temperature, which cannot reach boiling point, in more or less large pipes; the former circulated water at a high temperature in strong wrought-iron pipes of very small bore, rarely exceeding an inch in diameter. The high pressure system, as now carried out, was as innocuous and quite as effective and manageable as the low pressure. After referring to various examples in his own practice, of which numerous illustrations in sections and working drawings were exhibited, Mr. Robins concluded with the assurance that the practice of Civil Architecture could not be divorced from the experiences of Sanitary Science. There was plenty of room for specialists and *dilettanti* exponents—indeed, co-operation in overcoming the results of past carelessness was most needful; but the fact remained that dwelling houses, to be made healthy in the future, were and would still be the special province of professionel architects.

Dr. W. H. Corfield, at the invitation of the President, opened the discussion. A great deal had been said of late, he remarked, about the failure of architects to avail themselves of the advances of sanitary science; it was declared that they did not know their business; and all the failures in drainage and defects in ventilation of houses were laid to their door. For his own part, he had not found this to be the case. He had often met architects in consultation, and had always found them gentlemen who were able to understand all points that were raised, and he was glad to be able thus to acknowledge the courtesy with which he had always been met by members of the profession. Mr. Robins had told them that architectural practice could not be divorced from the experiences of sanitary science. He would go rather further, and say, if it had not been for the experiments that had been made by scientific men, no alteration in sanitary principles would have been carried out. For many years people had dealt with house drainage on a wrong system—that of bottling up foul air—and the erroneous method would probably have continued till now if it had not been for certain remarkable experiments, by which the real danger of sewer air—"gas" it was even now improperly called—was made apparent. It had been shown that enteric fever, and more recently that other diseases, were produced by a specific poison existing in sewer air, and communicable by contagion. Next it was ascertained that the poison was not the sewer air itself, but particles in that air, and it was now almost demonstrable that these particles were living germs, and the result was that people could now understand how they might prevent these particles from obtaining an entrance into their houses. But the practice of sanitary science had not been carried out, as the author said, "for a considerable number of years"—certainly not more than ten years—he might almost say six or seven. Disconnection of sewer and house drains had been shown to be essen-

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tial by two sets of experiments; one proving that the dangerous particles could pass by absorption through water, so that a trap was no bar to the movement of foul air through a drain; the other, that when foul air was disturbed, as Dr. Franklyn had shown, it would pass through a water trap, and would be dispersed in the air above, contaminating it. Thus, while a water trap would partially prevent the passage of particles, it could not prevent the passage of foul gas. But it was now possible to make a house perfectly secure against the entrance of typhoid fever, and should the fever be imported by any person, it need not spread. Acting upon this knowledge, he had been able to state that a well-drained school in which typhoid occurred need not be closed, as if precautions were taken, the contagion could not spread. Although the principles of sanitary science were now perfectly clear and simple, yet to put them into practice was most difficult, especially in the case of an old London house, where it sometimes seemed impossible to put it into an efficient and healthy condition without pulling down the entire structure. To tell people to get a book on the subject and read it and put their dwellings in order, was as absurd as to tell a man to read a book on amputation, and then experiment by cutting off a friend's leg. One of the most amusing things was to go into a house where a man had tried to cure its defects himself. Often in houses which had been put in order by professional men, sore throat, sewer diarrhoea, and similar diseases were noticed. These showed that it was insufficient to disconnect the sewer and house drain, but that the waste pipes of sinks, discharged even into an open chamber, needed trapping. Air passed, during the night, through the air-chamber into the house, and gave rise to the sewer diseases in question, so that a water trap was necessary here. The waste pipes of sinks were not proper ways for air to come into a house.

EXPLOSIVE GELATINE.

From Papers of the Royal Engineer Institute.

Explosive gelatine is a peculiar description of gun cotton, entirely soluble in nitro-glycerine, and forming with it a gelatinous or gummy substance, more powerful than nitro-glycerine, scarcely affected by water and giving out no trace of nitro-glycerine under the strongest pressure.

It can be rendered insensible to mechanical action, while retaining its power, by mixing it with certain substances soluble in nitro-glycerine, such as benzine, &c.

It is composed of 93 parts of nitro-glycerine, and seven of soluble gun-cotton.

The experiments demonstrated its insensibility to shock, to friction, and to the pressure or action of water; and further, that to produce complete explosion in a free state, and to develop the great force corresponding to its chemical composition, it would be necessary to use, even in its soft state, a peculiarly powerful detonator.

One gramme of fulminate of mercury was insufficient to detonate a charge in a a soft state, contained loosely in a tin case. Fragments of gelatine as large as a pin's head, or even of a small pea, were found scattered about after the explosion.

Under the blow of a pile engine, the gelatine was insensible to a blow of 3-5 kilogrammeters, while dynamite instantly explodes under one kilogrammeter.

The gelatine is unaffected by submersion in water, even at a temperature of 158° F., and showed no trace of exudation after eight days, at a temperature of 113° F.

From these properties it would appear very superior to dynamite for military purposes, provided a sufficiently powerful primer can be made to ensure complete detonation.

A new explosive suitable to all requirements has been prepared from this substance, and may be termed *gelatine explosive de guerre.* It is produced by add-

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ing to the gelatine a small proportion of camphor, a substance highly soluble in nitro-glycerine.

A very small proportion of camphor renders the explosive insensible to blows, even of projectiles at short range, it also enables it to resist the action of water, and imports to it an explosive force far superior to dynamite or compressed gun cotton.

For complete detonation a special primer is needed of extra power, composed of a mixture of nitro-glycerine with a description of nitro-cellulose, prepared in a particular manner.

The composition of *gelatine explosive de guerre* is—

Camphor	4
Explosive gelatine	96
	100

Explosive gelatine consisting of—

Nitro-glycerine	90
Soluble gun cotton	10
	100

In appearance it is gelatinous, elastic, transparent, and pale yellow in color.

Its density is 1-6, it can be cut with a knife, and under the severest pressure it shows no trace of nitro-glycerine. At temperature of 122° Fahr. to 140° Fahr. it softens a little, but seldom becomes greasy.

When inflamed in the open air it burns like dynamite or dry compressed gun cotton.

200 grammes were placed in a tin cylinder six inches long. When ignited with a slow match penetrating the middle of the charge, it burnt quietly with a long yellow flame, though the case was closed with a metal cover. When half the charge was burnt the cover was simply raised by the pressure, without any explosion taking place.

A composition of 10 parts of camphor and 90 of explosive gelatine may be exposed for a week to a temperature of 158° Fahr. without showing any signs of decomposition.

4-4708 grammes of the same composition in a watch glass were exposed for seven hours a day during two months to a temperature of from 104° to 122° Fahr.

No decomposition took place, merely a partial volatization of camphor and nitro-glycerine.

After the experiment the specimen still weighed 4-1239 grammes, so that the loss of weight amounted to only .3469 grammes, or 7-7 per cent. As nitro-glycerine becomes volatile at 104°, part of the loss is accounted for, so that half the camphor in the composition can scarcely have evaporated, though the circumstances were exceptionally favorable to evaporation.

Experiments are needed to determine the rapidity of evaporation of the camphor, and the effect of its volatilization on the properties of the composition.

The preservative action of camphor, especially at exploding temperatures, is extremely notable.

Thus pure explosive gelatine, slowly heated, detonates at 400° Fahr., or rapidly at 464°.

If 10 per cent. of camphor are added it will not detonate at all when slowly heated, but becomes diffused in sparks. When heated rapidly, it explodes at a temperature too high for measurement by ordinary apparatus.

Mixed with 10 per cent., or even 4 per cent. of camphor, this substance will not explode at the same temperature as gunpowder, viz., 570° to 600°, but simply burns, producing sparks.

It may be inferred from the above that its liability to explosion from a blow would be equally slight, especially having regard to the elastic, gelatinous consistency of the material.

It requires a peculiarly powerful fuse to ensure the certainty of detonation. The inertness of the composition increases rapidly with the proportion of camphor. With the addition of only four per cent. detonation cannot be ensured with two grammes of fulminate of mercury, a primer of compressed gun cotton, or a mixture of 75 parts of nitro-glycerine with 25 of gun cotton, as used in the Austrian service.

A special primer is therefore required. It is composed of 60 per cent. of nitro-glycerine, and 40 per cent, of a nitrous substance, obtained from cellulose by a peculiar process.

Owing to the composition of cotton, it is impossible to obtain from it tri-nitro-cellulose. In Abel's process much of the cotton is only partially nitrogenized, and

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some not at all, while Lenk's method is still less efficient.

If sulphuric acid be made to act upon cotton a white powder is obtained, named hydro-cellulose. This substance is extremely susceptible to the action of nitric acid. The result is, as regards explosive force, a highly nitrogenized description of cellulose.

This new gun cotton appears in the form of a fine powder resembling flour, but exhibits under the microscope the specific structure of cotton. It is not a great absorbent of nitro-glycerine like Abel's or Lenk's cotton, which are divided by mechanical means, neither does it share their property of becoming gelatinous with this liquid.

The mixture of 60 per cent. of nitro-glycerine with 40 per cent. of nitro-hydro-cellulose yields a soft, white, soapy, and entirely homogeneous substance. 20 grammes can be placed in an Austrian cartridge, which will hold but 15 to 17 of the regulation composition, and thus furnishes a primer capable of exploding *gelatine explosive de guerre*, and surpassing in detonating power all known exploding agents.

THE JORDAN BAROMETER.

From "The Builder."

It is impossible to foresee the result of the perfecting of any scientific instrument. It is rarely the case that such an instrument is—like the spiders among *insecta* and their allies—born in the form which it will maintain through life. Such, however, was the case with the weather-glass of Pascal. The best mercurial barometers of the present day are in principle, and almost in detail, identical with the tube, which that great genius carried up the Puy de Dome for his memorable experiment. The great defect of the mercurial barometer is the narrow limit of its movement. A difference of ten per cent. in the atmospheric pressure, which is about the maximum to be obtained at any fixed point on the surface of the earth, only causes a difference of 3 in. in the height of the column of mercury, and it is difficult to read the barometer more closely than to the tenth of an inch. The ball-like, or cup-like, form of the top of the mercury gives some indication as to the actually upward or downward tendency of the barometric movement; but the desirability of a more visible display of the force of atmospheric pressure is undeniable.

Extreme delicacy, no doubt, is obtained by the use of an aneroid, furnished with vernier and magnifying glass. But the aneroid is better suited for observations involving change of place than for those made successively on the same spot. Like the old-fashioned wheel barometer, the aneroid usually requires a tap, to see that the needle is freely moving; and this is but a clumsy means of making a delicate observation. Years ago we remember, in the window of an optician in Liverpool, an inclined barometer. The upper 3 in. or 4 in. of vertical tube were replaced by 5 ft. or 6 ft. of inclined tube, so that by placing the graduation at right angles to the latter, the intervals of change were magnified from twelve to fifteen times. We are not aware how the ingenious modification acted. Those of our readers who were at the meeting of the British Association in Birmingham, some fourteen years ago, may remember that one of the lions of the place was a water barometer, erected in the house of an amateur, which seemed almost to breathe like a living being. A water barometer was made by Professor Daniell for the Royal Society in 1830. The indications given by this instrument (the movement being about twelve times as great as that of the mercurial column) are very distinct. But the variation of temperature exerts such an influence on the vapor rising from the water within the tube as to interfere with the accuracy of the instrument. In fact, it is not a barometer, pure and simple, but a combination of barometer and thermometer.

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Mr. Jordan, of the Museum of Practical Geology in Jermyn-street, has met, and it seems safe to say, has overcome this defect in the water barometer. He has substituted for water, pure glycerine, the specific gravity of which is 1.26—or only one-fourth more than that of water, And glycerine possesses the unusual advantage of combining perfect fluidity with a boiling point of 440 Fahr., and a correspondingly low freezing point. Thus, it raises no vapor to be affected by heat in the top of the tube, nor will it be injuriously affected by frost. The only defect of the substance is the readiness with which it absorbs water from the atmosphere. This has been met by Mr. Jordan, by the ingenious device of giving the glycerine a waterproof coat, or, in other words, floating a layer of petroleum on the surface of the glycerine in the cistern. Thus, a barometer of extreme delicacy, and as little liable to get out of order as the mercurial barometer itself, has been placed at the service of science.

One of these barometers has been constructed at Kew Observatory; a second at the Museum of Practical Geology in Jermyn-street; a third at the South Kensington Museum; and a fourth at the office of the *Times* newspaper. This journal has commenced the publication of two hours' reading of the instrument, plotted on the natural scale. The unusual weather, which has prevailed during the first week of these graphic indications, has been illustrated by the very visible movement of the surface of the glycerine. What is now most to be desired is the erection of an adequate number of these instruments at certain well-selected points in the island, and the publication of the contemporaneous movements of the column. The strong accentuation of the variations, already published, is such as to raise the hope that much valuable information may be secured by the proper multiplication of these delicate observations.

HISTORY OF ZERO.—"Zero" on the common thermometer, like the fanciful names of the constellations, is a curious instance of the way wise men's errors are made immortal by becoming popular. It may be worth while to say that the word itself (zero) comes to us through the Spanish from the Arabic, and means empty; hence, nothing. In expressions like "90° Fahr." the abbreviation, Fahr., stands for Fahrenheit, a Prussian merchant of Dantzic, on the Baltic Sea. His full name was Gabriel Daniel Fahrenheit.

From a boy he was a close observer of nature, and when only 19 years old, in the remarkably cold winter of 1709, he experimented by putting snow and salt together and noticed that it produced a degree of cold equal to the coldest day of the year, and that day was the coldest that the oldest inhabitant could remember. Gabriel was the more struck with the coincidence of his little scientific discovery, and hastily concluded that he had found the lowest degree of temperature known in the world, either natural or artificial. He called the degree zero, and constructed a thermometer, or rude weather glass, with a scale graduating up from zero to boiling point, which he numbered 212 and the freezing point 32, because, as he thought, mercury contracted the 32d of its volume on being cooled down from the temperature of freezing water to zero, and expanded 180th on being heated from the freezing to the boiling point.

Time showed that this arrangement, instead of being truly scientific, was as arbitrary as the division of the Bible into verses and chapters, and that these two points no more represented the real extremes of temperature than "from Dan to Beersheba" expressed the exact extremes of Palestine.

But Fahrenheit's thermometer had been widely adopted with its inconvenient scale, and none thought of any better until his name became an authority, for Fahrenheit finally abandoned trade and gave himself up to science.

The three countries which use Fahrenheit are England, Holland and America. Russia and Germany use Réaumur's thermometer, in which the boiling point is counted 80 degrees above the freezing point. France uses the centigrade thermometer, so called because it marks the boiling point 100 degrees from freezing point. On many accounts the centigrade system is the best, and the triumph of convenience will be attained when zero is

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made the freezing point, and when the boiling point is put 100 or 1,000 degrees from it, and all the subdivisions are fixed decimally.

If Fahrenheit had done this at first, or even if he had made it one of his improvements after the public had adopted his error, the lack of opportunity which was really his, would have secured to his invention the patronage of the world.

LABOR OMNIA VINCIT.—We have recently had brought to our notice a remarkable example of the truth of the adage that labor conquer all things.

In 1866 a young man who had been blind from his birth applied for admission to Columbia College. After passing an excellent examination, he was admitted. He took at once a good rank in scholarship, which constantly improved, till at the close of his four years' course he was adjudged worthy of delivering the Latin salutatory at Commencement, the second honor in his class. He conquered his position by the most assiduous labor, under circumstances that might have appalled even a courageous man in the possession of all his faculties. He had prepared under his direction, or prepared himself upon card-board, in raised letters and diagrams, the text of the every-day lessons in classics and the necessary mathematical figures, such preparation often costing him three hours' labor for one lesson. With his raised letters and diagrams he could, by his delicate touch, read and demonstrate with great facility. His mind was eager and incisive, and his recitations became models of clearness and accuracy. He took high rank in every study, but excelled in mathematics. Difficulties in this seemed to delight him. His fine mind and unflagging spirit never rested till all difficulties had been overcome, and he was master of the subject. After graduation, he taught private pupils, and in such intervals of leisure as he had he continued and extended the study of mathematics. Some two or three years ago, he found that the satisfactory solution of a problem upon which he was engaged required a knowledge of the calculus of variations—an abstruse branch, to which he had paid little or no attention. He immediately, *suo more*, began a thorough investigation. He gathered, by purchase and from private and college libraries, all that was to be had upon the subject. He found that nothing of importance concerning it had ever been published by an American author; that the only systematic work upon it that ever appeared in English, published in England thirty years ago, was out of print, very difficult to obtain, and that since its publication the subject had been greatly extended and improved by the labors of English, French, and German mathematicians; that the results of these labors were inaccessible to the general reader, being contained in communications to mathematical journals and learned societies, or in certain special works. He thereupon undertook the preparation of a treatise which should present in a simple manner everything at present known concerning this branch of mathematics. He knew nothing of the French and German languages; he had translated to him, often by people who could simply translate the words and not the sense to him, the French and German essays; and thus, in physical darkness, but in the clear light of his own mind, he wrought simplicity out of complexity. The only amanuensis accessible to him was a person ignorant of mathematics, which increased the embarrassment under which he labored. To this amanuensis he dictated his work, which is now completed, and is believed to be the only thorough, simple, and systematic treatise on the subject in the English or, perhaps, in any other language. The name of this work, which would be a credit to any man, and which under the circumstances, is simply marvelous, is *A Treatise on the Calculus of Variations*, by LEWIS B. CARLL, of Flushing, Queens County, New York.

He has one more difficulty to overcome in connection with it, and that is in its publication. His publisher* requires subscriptions for 300 copies before he will undertake it, and these Mr. CARLL, besides giving away his labor of years, has courageously undertaken to procure. There can be no doubt that he will succeed, for surely labor, properly directed, conquers all things.—*Harper's Weekly.*

* The work will be published by D. VAN NOSTRAND, 23 Murray Street, New York City, who will give any information with regard to it that may be desired.

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REMOVAL OF SILT FROM THE BACK OF RESERVOIR DAMS IN ALGERIA.

By MARTIN CALMELS.

From "Abstracts" of the Institution of Civil Engineers.

SOME experiments were made last October, at the Sig reservoir, on the Author's method for removing silt from reservoirs by means of jets of compressed air. Full details are given of the apparatus employed, which consists essentially of a compressor, an accumulator, and a pipe for directing the jet. The accumulator is made of three galvanized plate-iron cylinders, each 6½ feet long, 13 inches in diameter, and nearly ¼ inch thick, and calculated to resist a pressure of 85 lbs. on the square inch. A pipe, 1 inch in diameter, conveyed the compressed air from the accumulator, over the reservoir dam and down the other side, on to a double pontoon floating on the reservoir lake, through the centre of which the tube of the air jet is directed as required. Two india-rubber tubes, each 50 feet long, serve to connect flexibly the iron pipe passing over the dam with a floating pipe, and the floating pipe with the jet. The nozzle at the end of the directing tube is conical, and has eight holes at the side $\frac{1}{10}$ inch in diameter. The rate of the current of air, under a pressure of 57 lbs. on the square inch, in a depth of water of 16 feet, would amount to 1,600 feet per second. With an 8 HP. engine, the jet can be worked continuously under a pressure of 5 or 6 atmospheres. Another jet with a single orifice, ½ inch in diameter, has been made for working at a lower pressure. The action of the jet proved very satisfactory in stirring up the silt; and by opening the sluice gates at intervals, after working the jet in the deposit near the dam, a considerable quantity of silt was discharged with the water. As the silt, though sometimes forming a hard crust at the surface in dry weather, remains fluid below, the jet would gradually lower the deposit all over the reservoir by merely working near the dam, as the silt higher up would by degrees slide in and fill up the void made at the dam. The process, morever, would serve not merely for keeping new reservoirs clear, but for removing accumulated masses of deposit from old reservoirs. By proper management, the Author considers that a large deposit might be gradually removed without interfering with the agricultural interests; and that by introducing the stirred-up silt, at suitable times, into the irrigation canals, it might be beneficial in fertilizing the land. Also by removing the silt close to the dam, which frequently prevents the lifting of the sluice gates, the Author thinks a better system of gates might be adopted, which, by being contrived to open rapidly, would increase the scouring action at the sluices.—*Annales Industrielles.*

CALCULATION OF THE STRENGTH OF CYLINDRICAL VESSELS. — The author draws attention to the inaccuracy of the formulæ given by Barlow, Brix & Lamé, for calculating the strength of cylindrical vessels, and states that they are all based on the tacit assumption that *k*, the admissable stress on the material of the cylinder, is identical with the greatest occurring tension; this, the author asserts, is not, as a rule, the case; in general it is not the greatest stress existing in any part of the body under consideration which is of importance, but the greatest elongation (or compression), the latter being only in special cases—simple tension (or compression), bending or shearing, combinations of tensile (or compressive) and bending, or shearing and torsional strains—directly proportional to the maximum stress. Grashof, whose formulæ are also quoted, has

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taken account of this, but neglected the influence of the pressure in the direction of the cylinder axis, as have also Barlow & Brix.

The author, in developing his formulæ, avoids the inaccuracies mentioned, and arrives at the following results:

for internal pressure p

$$r_2 = r_1 \sqrt{\frac{k+0.4p}{k-1.3p}};$$

for external pressure p_0, assuming that collapse is out of the question,

$$r_2 = r_1 \sqrt{\frac{k}{k-1.7p_0}};$$

where r_1 = inside radius of cylinder,
r_2 = outside " "
k = admissable tensile strain.

—(*C. Bach, in Zeitschrift des Vereines Deutscher Ingenieure*).

THE FAILURE OF A DOCK WALL IN THE EAST INDIA DOCKS.

By LIEUT. H. D. LAFFAN, R. E.

From the Papers of the Royal Engineer Institute.

About the beginning of July, 1879, a serious settlement took place in the south wall of the East India Import Dock. The wall in which the failure occurred was built of brick and stone lime mortar. The brickwork was apparently very good, the wall having in one place sheared straight through the bricks, leaving the joints undisturbed.

For a length of about 700 feet the wall had sunk down to a depth of several feet, and in its final position had assumed an irregular wavy outline, the greatest bulge (at the footings) being 7 feet 3 inches, and the greatest subsidence 5 feet 3 inches. The forward movement, however, was almost entirely confined to one point, and was probably caused by a heavy crane fixed just behind the top of the wall on an iron framework. As the wall sank the crane fell backwards, acting with a leverage upon the wall and driving it forwards.

At the western end of the settlement the wall had sheared downwards, leaving a fissure 1 foot wide, with a step 2 feet high at the top; at the east end the shearing was distributed over a number of smaller fissures. No part of the stuff at the back of the wall had found its way into the dock, but had sunk down, forming a trench behind the wall, in which, in some places, there was a depth of as much as 15 feet of water.

A large warehouse, only 50 feet distant from the edge of the wall, had shown no sign of settlement; this may be accounted for by the fact that they were built on a solid layer of concrete, 13 feet thick. The dock wall in which the failure occurred was built without a foundation of piles, upon cross planking, laid on gravel and sand some 2 feet deep, overlying running sand, and the settlement appears to have resulted from the sand being drawn away from under the wall.

The immediate cause of the settlement appears to have been the tapping of the running sand in the course of excavating works in connection with the Midland Railway Docks, about a quarter of a mile distant, when a "blow" ensued which covered in the works with sand to a considerable depth. The sand was allowed to run for several days, and while it was running the settlement occurred in the wall of the East India Dock. At about 5 A. M. one morning the wall sank down suddenly without any previous warning, the greatest subsidence at first being 3 feet, but it afterwards continued to sink gradually as long as the flow of sand in the Midland Railway Works continued, and when this was stopped the settlement ceased.

At one time there was a channel from the bend of the River Lea, into the River Thames, about where the Midland Railway Docks now are, and although the channel has been stopped, there is probably still a creek of sand running in

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this direction through the East India Import Dock, and under its south wall, which has been tapped by the Midland Railway Company. The sand had thus, in all probability, been drawn away from under the wall, which, after supporting itself across the gap for a time, after the manner of a beam, eventually gave way suddenly under its own weight.

This accident has occurred at a time when there is a pressing want of accommodation on the quays of the East India Docks; it has, therefore, been thought desirable to widen the wharf on this quay, as well as to restore it as rapidly as possible. For this purpose a wooden staging is to be erected about 30 feet to the front of the present wall; the wall itself will be left as it is, and a mass of concrete, resting against its base and sloping up to the top, will be laid between the wooden staging and the wall, in order to prevent any further forward movement.

STREET LIGHTING (ELECTRIC) IN LONDON.

THE meeting of the City Commission of Sewers was held recently to consider the tenders submitted for lighting during one year three districts of the City, in answer to the applications made some time since. The offers from the representatives of four different systems were considered. The first district comprises Blackfriars Bridge, New Bridge Street, Ludgate Circus, Ludgate Hill, the north side of St. Paul's Churchyard, and Cheapside as far as King Street. The particulars of the tenders for this district were as follows:

—	Cost of working for 12 months.	Cost of fixing and removing.	Total.	Number of lights.	Candle power per light.	Total candle power.	No. of gaslights replaced.
	£	£	£				
Brush.....	660	750	1410	32	2000	64,000	150
Crompton...	2007	500	2507	17	4000	68,000	152
Siemens....	2050	1650	3700	29	—	47,000	144
Jablochkoff.	1500	1550	3050	48	500	24.000	144

The 29 Siemens lamps comprised 23 small ones of 500 candle power each, and 6 large ones each of 6000 candle power. The Committee recommended that the tender of the Anglo-American Electric Light Company (the Brush system) should be accepted. The second district embraces Southwark Bridge, Queen Victoria Street, the lower part of Queen Street, and Queen Street Place. The tenders considered for this district were as follows:

—	Cost for 12 months.	Fixing and removing.	Total.	Number of lights.	Gas lights replaced.
	£	£	£		
Crompton.....	2167	560	2727	16	176
Jablochkoff.....	1580	1350	2930	12	161
Siemens..... ...	1850	980	2830	31	164

The 31 Siemens lights would consist of 26 small and 5 large lamps. It was recommended that the contract for this district should be given to the Electric and Magnetic Company (Jablochkoff system).

The third district refers to London Bridge, the upper part of Queen Street, Cheapside, King Street, Guildhall Yard, the Poultry, Mansion House Street, the Royal Exchange, King William Street, and Adelaide Place. The tenders considered for this section were :

—	Cost for 12 months.	Fixing and removing.	Total.	Number of Lights.	Gas lights replaced.
	£	£	£		
Crompton...	2475	650	3125	18	132
Seimens.....	2270	1455	2726	32	138

The Siemens' lights will consist of 26 small and 6 large ones. The lighting of this district was awarded to Messrs. Siemens Brothers. Some idea of the different modes of installation proposed

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will be gathered from the following particulars: The Anglo-American Light Company will fix their lamps on separate posts, not less than 13 feet above the ground. Overhead wires will lead from the company's Victoria Works, Vine Street, Lambeth, where the power will be located, and then from post to post, overhead, except across the streets, when they will be carried underground. Messrs. Crompton & Co. suggested employing lamps capable of sliding up and down posts, or suspended across the streets, and to be lowered by cords and pulleys. Upon the bridges the lamps would have been carried on posts 35 feet high. The electric and Magnetic (Jablochkoff) Company will carry out the same system as on the Embankment, the wires being hung from lamp to lamp, and carried over the crossings, on high posts. Messrs. Siemens Brothers will employ large lamps in clear glass globes, with umbrella-shaped reflectors, placed on posts 70 feet or 80 feet high, and small lamps in partly or wholly frosted glass globes, on 20 feet standards. The wires will be laid underground, and the light-producing plant will consist of two 12 horse power semi-portable engines, seven medium-sized dynamo-electric machines, and the alternate current machines, with their excitors. In making their report and recommendations, the Street Committee stated that they had been guided not only by the prices given in the tenders, but by the effect produced with the different systems in actual operation, all of which they had seen.

REPORTS OF ENGINEERING SOCIETIES.

Boston Society of Civil Engineers.—At the December meeting a memoir of Ephraim N. Winslow, late Chief Engineer of the Old Colony Railroad, was read by Mr. Doane.

A description of the Old Mill Dam wall was presented by E. W. Howe.

A paper on "Additional Width of Gauge on Railroad Curves," was read by Thos. Doane.

Engineers' Club of Philadelphia.—The annual election in January resulted in the choice of the following officers:

President—Strickland Kneass; *Vice-President*—Henry G. Morris; *Recording Secretary*—Wilfred Lewis; *Corresponding Secretary*—Howard Murphy; *Treasurer*—A. R. Roberts; *Board of Directors*—Frederic Graff, Rudolph Hering, J. J. De Kinder, T. M. Cleemann, Geo. Burnham, Jr.

The papers presented at the meeting of January 15th, were the following:

"Canal Routes Across the Isthmus of Panama," by Col. James Worrall.

"Progess and Methods of the Geological Survey of Pennsylvania," by Charles A. Ashburner, M. E.

"The Use of Dynamite for Blasts," by W. Rodman Wharton, C. E.

"Notes and Illustrations of Mine Topography," by Charles A. Ashburner, M. E.

"Estimates and Improvements in Diamond Drilling," by Chas. E. Billin, M. E.

The American Society of Civil Engineers.—The growth of the Society leads to a demand for more ample space.

A circular has been issued to members, and is to be extended to others who are interested in the advancement of engineering, the purport of which is, that the Board of Direction solicits contributions to a building fund, the amount of which shall be $25,000 or $30,000. The names of contributors to the fund will be regularly enrolled and published in the proceedings. A subscription of $100 entitles the giver to a copy of the monthly publications for life.

The Polytechnic Association of the American Institute held its regular weekly meeting on the evening of the 6th inst. Thomas D. Stetson, presiding.

A newspaper scrap was read announcing a newly-discovered process for the preservation of dead bodies, originated in Germany and patented here; but the patentee had been induced to abandon his patent and make it public property for the benefit of the world. A liquid was made by which the bodies were embalmed by being saturated and impregnated with it. Three thousand parts water, one hundred alum, sixty potash, twenty-five common salt, twelve saltpetre and ten arsenic acid was made the first composition. Then to ten parts of this, four parts of glycerine aud one of methyl alcohol were added. Bodies preserved by this were alleged to fully retain their form, color and flexibility for years.

In the discussion it was doubted that the color would be preserved. There were compounds which would preserve human bodies very prefectly, if they could be thoroughly impregnated before decay had commenced. A company in this city, the New York Sanitary Company, furnish a fluid and instruments for applying it, by which the interiors are very thoroughly impregnated before decay commences. Then a moderate treatment on the surface with the same or other preserving fluid insures the preservation of the body in a high degree of perfection for a long period. The body of the well known actor, Mr. Porter, who was killed in Texas, was preserved by the aid of this process and brought to this city, and seen by his friends at the funeral fourteen days after death.

An account was read from *Iron* of a process of printing many colors at one operation, alleged to be in successful operation in France. A solid block was formed in Mosaic of differ-

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ent colors, using blocks of pigments all capable of being acted on by a chemical or combination of chemicals. A thick mass of this is mounted in the press, planed off smooth, and then wetted rapidly on the surface with the proper fluid, and the paper or other material placed thereon and pressed. A clear impression is thus obtained in all the colors, and in the case of textile fabrics the color goes completely through their substance. After exposure for a brief period to heat, to drive off the fumes of the chemicals employed, the work is finished.

Mr. MacDonald said he had assisted in trying similar experiments in this country. In those experiments glycerine was used, and the printed impressions had the peculiarities due to the presence of glycerine, that they remained damp. The process, so far as he had known it, had been always a failure. The sharpness of the impressions would be satisfactory to some, but not to a good printer, and the character of the work generally was inferior.

Mr. Blanchard developed on the blackboard a mode—original with him, for computing the strains on the different parts of bridges. Eddy, Stoney, Dubois and others had analyzed with immense fineness, but their methods were too complicated. It could be done much more simply. The relative strains on every part were ascertained by geometrical figures. The operation was rapid and sure. It was an improvement on the ordinary diagram for the decomposition of forces. The vertical strains were represented by horizontal rather than vertical lines.

The discussion following developed singular anomalies in the failure of bridges. The Montmorenci bridge, near Quebec, after bearing immense loads for a long period, fell suddenly with nothing on it. It appeared that the fracture, of iron wrought under continued strain, was a gradual process, the catastrophe occurring as the result of a slow failure which had been initiated much earlier. Mr. Hudson referred to the failure of the chain bridge across the Merrimack River in 1826 after a heavy snow storm.

The President referred to the great perfection which theoretical and practical science has been brought in modern bridge building, as exemplified in the costly East River Bridge, which we hope will prove, as it promises, a master-piece of the art. He also mentioned the two famous bridges near each other at North Bangor, in Wales—one, a suspension bridge completed in 1825, before the superiority of small wire cables for such purposes had been established. Wires were immensely easier to stretch across one at a time and were found much superior in strength for a given weight when completed. That bridge was built with what are sometimes termed pitch-chains, bars of iron laid three or four abreast and knuckled together by transverse pins through their ends. It continues to be used for general carriage traffic. Near it is the famous tubular bridge engineered by Stevenson & Fairbairn, which carries the railway trains between Anglesea and the main island of Great Britain. Shipping moves under both bridges through the Menai Straits.

An extract read from the editorial correspondence of the *Philadelphia Press* of last summer, developed a long conversation with one of the leading silk manufacturers of Lyons, in which he sadly admitted the competition, dangerous to their industry, of Americans, in the silk manufacture. In the discussion which followed, it was stated that there are now about 200 separate manufactories in America for woven and sewing silks. American manufacturers load their silks with less foreign matter and make an article which is superior in wear but not as brilliant in gloss. Paterson, and other points, manufacture ribbons with eminent success. Hartford manufactures dress goods of sombre colors superior to any in the world. We import about 7,500 tons per annum of raw silk and manufacture it here. The raw silk made in this country is slight. Wages are too high. It requires cheap labor as in Italy, China, &c. Machinery has not yet succeeded in reeling cocoons.

But immense areas of our country have mild winters and are every way favorable for the silk worm. We can raise cocoons and ship them abroad to be reeled and returned. We are producing cocoons largely in North Carolina and California.

A paper read by Professor De Volsen Wood opened the main subject of the evening, the "Relations of Machinery and Labor." He held that the present era of machinery has induced great revolutions in labor and laborers, but the general effect is eminently beneficial.

The farmers of Ohio opposed railroads in the belief that they would diminish the demand for horses and oats, until it was shown that the introduction of railroads resulted in an increased price for both, in every instance. A machine which made one man do the work of ten, at first sight appeared to dispense with the labors of nine, but labor is more constantly in demand and better paid than before machinery was introduced. A farmer's wife in the West told him that their reaping machine, by reducing the number of men to feed during harvest, had lightened her work more than her sewing machine. The increased production of the earth must result in greater wealth to the world. Fifty thousand reaping machines involve in the first instance, a quickened demand for metal, wood, skilled labor and means of transportation. It calls for buildings, clerks, and agents. The wealth it produces calls for buildings, stock, carpets, music, books, and works of art. Thus, apparently unconnected branches of business are benefited by the reaping machine.

The discussion following questioned one proposition: It was doubted whether the reign of machinery tended to narrow the faculties by confining a man to one branch of labor. Formerly a long apprenticeship trained the faculties to the production of a wrought-nail or a pin-head and there stopped. The apprentice system is gone. There is danger from its absence, but so far, in America at least, the intelligence developed by the schools, gen-

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eral and technical, have successfully taken its place, and all are mobile. Our great manufactories, with their hum of machinery are schools to every young man and warn him that he should be ready for emergencies. We have no indolent rich, no idle class except the tramps, and they are disappearing. All can, and do, work with head or hands, and nearly all can change successfully from one business to another with only three weeks of special training.

ENGINEERING NOTES.

SAFETY ARRANGEMENT FOR WATER PIPES. In order to obviate the very common evils connected with the bursting of water pipes in winter, Herr Weissbarth has contrived an arrangement (we learn from the *Deutsche Industrie Zeitung*) by which any water that may escape thus is carried off into the street drain or a cesspool, and, at the same time, a cheap mode of heating the whole pipe system with a single gas or petroleum flame is rendered possible. The entire system of water pipes, which, as in every right arrangement, must have, in all its branches, falls toward the ascending pipe, is inclusive of the ascending pipe) inclosed in sheet zinc pipes of 5 to 8ctm. internal diameter; so that water finding exit at any part of the system gets into the inclosing pipe, and is carried away. The inclosing zinc pipes, about 1 meter long, are not soldered at the joints; but stuck into each other like gutter or waste pipes, and the water pipes, of lead or iron, are fixed in the others by means of rings with small projecting pieces bent at a right angle, which catch in metallic tholes soldered on the interior of the zinc pipe. The lowest inclosing pipe has a bottom, through which the water pipe passes tightly, and close above this is the tube by which the escaping water is carried off to the drain. In order to get at the water pipe without having to take the zinc pipes out of each other, some of these are furnished with doors 70 to 75ctm. long and 5 to 6ctm. wide, which are easily slid within the tube, as they are led above through a soldered metal ring, and below through packing; the latter at the same time prevents the water flowing out between the doors and the pipe; moreover, the longitudinal borders of the doors are packed interiorly, so that the water follows the packing and does not issue by the door. The fixing of the zinc tubes to the walls is effected with rings on which they are supported with noses. Branch pipes are soldered into the main pipe. When, in a branch pipe, stopcocks occur, the inclosing pipe is there perforated for the spindle and stuffing box. In the longer branch pipes, as in the vertical ascending pipes, doors must also of course, be introduced in the inclosing pipes, the openings being naturally on the upper side. At places where the ascending pipe is exposed to cold, as, *e. g.*, in water closets or entrance halls, the arrangement permits readily of a warm air-current being produced in the inclosing pipe, by means of a gas flame (which may also serve in illumination). To this end the pipe is furnished with an oblique branch directed upwards, and bent round to terminate in an iron or brass funnel, under which the gas or petroleum flame burns. The heat then passes into the inclosing tube. In the air box above holes are provided to let the air escape, and good ventilation may thus be secured.

In order to facilitate repairs, the water pipe, at the middle of the doors of the inclosing pipe, is formed with brass connecting screws. But the use of the ordinary soldered junction does not present any hindrance by reason of the zinc tube. Nor are any other serious difficulties, it is said, encountered in the working of the system.

UNITED STATES SUBMARINE SURVEYING.—The present year's submarine survey work of the United States Government was undertaken with the object of determining the exact relation of the fauna of the Atlantic Ocean with that of the Gulf of Mexico and the Carribean Sea. The deep sea soundings ranged chiefly between 450 and 800 fathoms, and the work begun in June last, was carried on about 120 miles from the coast, and, generally parallel to it, commencing south of Cape Hatteras. The sea bottom has been shown, by these explorations, not to be gently sloping, but there was found the continuation of the plateau of which the northern portion extends as far as Cape St. George, the southeasterly limit reaching to the Bahama Banks. The work of exploration was confined during the past season to the western slope of the plateau, the sides of which are so steep, that in the distance of a few hundred feet, the depth of soundings increased from 100 to 450 fathoms. This side of the plateau is covered with a rich deposit of mud and alluvium, gathered from the discharge of numerous rivers and washed off the top of the plateau by the action of the Gulf Stream. The result of this action has been, that while no animal life has been found to exist on the top of this submarine highland, except certain coral formations, the conditions of the slope are highly favorable, and the numerous specimens obtained showed that, generally, the animal life corresponds with that in the Gulf of Mexico and the Carribean Sea. During the course of the survey, work was continued day and night, and eight dredgings were generally made during the twenty-four hours.

THE NEW TAY BRIDGE.—The sketch plans prepared by Mr. W. H. Barlow, C. E., London, in connection with the Parliamentary notices already published for the erection of another Tay Bridge, have been issued. While these plans do not show the structural details, it is understood that the bridge is to be of sufficient width to admit of a double line of rails being laid, and that in the arrangement of the girders the rails will be laid partly along the lower and along the upper booms, the permanent way being enclosed on each side by a strong iron parapet. The new bridge is to be erected a little to the west of the present one, the intervening space between the centers of the bridges being about 50 feet in width, and

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the course it takes is in a line with the old bridge. At the north shore it joins the existing viaduct at Magdalen Yard Point. In the bridge there will be 75 spans in all, the four highest being opposite the four broken piers at the south end of the gap in the present bridge. Their width will be 229 feet each, and height 77 feet above the high water level of ordinary spring tides, being 11 feet lower than the highest spans in the old bridge. The height of the first span on the Fife side is to be 65 feet, and the 22 succeeding spans gradually decline in height to 60 feet 6 inches. The four spans, 77 feet high, follow, and then the height of the remaining spans corresponds to the declinature of the bridge towards the north shore, where the spans are 23 feet high. The width and height of the different spans, beginning from the Fife shore, are as follows: One 100 feet span, 65 feet high; ten 106 feet spans, varying from 65 to 63 feet high; twelve 132 feet spans, varying from 63 to 60 feet 9 inches high; one 130 feet 6 inches span, 60 feet 6 inches high; four 229 feet spans, 77 feet high; one 229 feet span, 74 feet 9 inches high; one 211 feet span, 72 feet 9 inches high; two 229 feet spans, varying from 72 feet 9 inches to 68 feet 6 inches high; one 211 feet span, 66 feet 6 inches high; four 229 feet spans, varying from 66 feet 6 inches to 58 feet high; one 148 feet span, 40 feet high; eleven 117 feet spans, varying from 40 feet to 27 feet 6 inches high; twenty-four 63 feet spans, varying from 35 feet to 19 feet 5 inches high; two skew openings, 50 feet span each, and 23 feet high: six 27 feet spans, 23 feet high; three 27 feet spans, somewhat less in height, and last of all the present arch span 100 feet in width and 18 feet in height, which crosses the esplanade on the Dundee side of the river. The gradients are shown to be as follows: From the first span at the Fife side to the twenty-second the line has an inclination of 1 in 733, then it becomes level, and continues so for about 1000 feet, when it begins to fall towards the north shore at the rate of 1 in 114, until it reaches 1 in 76 at the viaduct, and at about that gradient the line is carried into the Tay Bridge Station, where it becomes level. The plans show the abandonment of the present objectionable junction of the Newport line at the south end of the bridge, and the substitution of another junction, which will likely be satisfactory.

IRON AND STEEL NOTES.

THE Customs' returns for the past month show that there has been an export of 83,905 tons of pig iron from English, Scottish, and Welsh ports, and that Middlesbrough exported more than half of this—44,848 tons. Barrow-in-Furness ranks second, having exported 8,230 tons; and then follow Glasgow, with 7,655 tons; Newcastle, 5,081 tons; Grangemouth, 3,650 tons; Liverpool, 3,454 tons; West Hartlepool, 3,360 tons; Whitehaven, 2,760 tons; Stockton, 1,878 tons; and Troon, 1,700 tons. None of the other ports enumerated have shipped more than 655 tons. Of bar and bundle iron, the largest shipment—10,904 tons—is from Liverpool, the amounts from all other ports being comparatively small. Of rails, Hull, Liverpool, Barrow, Middlesbrough, and Cardiff—in the order named—were the only ports exporting large quantities.

IN a paper "On the Determination of Phosphorus and Silicon in Iron and Steel," in Dingler's Polytechnisches "Journal," Mr. A. E. Haswell describes a new method of analysis, in which the whole of the electro-negative substances present in the metal are obtained in the insoluble residues, the iron being completely separated in solution as the first operation. The sample, in the form of filings or borings, is treated with a 7 per-cent. solution of double chloride of copper and ammonium, at the lowest possible temperature in a corked flask. About twelve hours are required to effect the solution, the flask being frequently shaken. If the proper equivalent quantities of the double copper salt are taken, the iron will be completely dissolved as ferrous chloride, free, or nearly so, from copper, while the carbon, silicon, sulphur, and phosphorus will remain in association with the reduced sponge of metallic copper. This, when carefully washed, is dissolved in nitric acid, the silicon determined by evaporation to dryness and calcination, and the phosphorus by precipitation, first with molybdic acid, and then with magnesia in the usual way. The author gives several examples showing that the molybdic acid precipitation is not affected by the presence of copper salts in the nitric acid solution.

STEEL MAKING IN CHINA.—In the manufacture and use of steel, the Chinese appear to have attained a very early and remarkable proficiency, Chinese records do not enlighten us as to the precise period at which the art of reducing metals from their ores became known in that country; but it is evident that it must have been some centuries before the Christian era. Mention is made of steel in the most ancient of the Chinese writings, and Leih-tze, an author who flourished about 400 B. C., described the process by which it was made. In the Yu Kung section of the Shoo King, Book I., it is stated that among the articles forming the tribute of Yu were nautical gem stones, iron, silver, steel, stones for arrow-heads, &c. Legge points out that, in the time of the Han dynasty, ironmasters were appointed in several districts of the old Lian-Choo to superintend the iron works. With the exception of this passage, however, it is considered probable that there is no distinct allusion to iron in Chinese writings older than 1000 B. C. Steel continues to be manufactured in China up to the present day. Mr. James Henderson, a commissioner of Li-hun chang, the governor-general of Chillili, a minister of the young King of China, states that the "steel which comes to Tein-tsin from the Upper Yang-tse is highly prized, and bears much higher prices than the Swedish steel imported into China."

SPANGENBERG'S EXPERIMENTS ON THE STRENGTH OF IRON AND STEEL.—A Werder testing machine, maximun pull 100,000 kilograms (100 tons) was erected, and a Klebe

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measuring apparatus was supplied, measuring to $\frac{1}{5000}$ millimeter ($\frac{1}{125000}$ in.), as well as various other instruments for conducting the experiments. One series was designed to test the truth of Wöhler's three laws, which are:

(1) Fracture may be produced by the continual repetition of oscillating stresses, all of them much below the breaking stress. It is the differences of strain, defined by the extent of the oscillations, which then produce fracture.

(2) The absolute value of these stresses only enters into the question so far that the greater this value the smaller are the differences which will finally produce fracture.

(3) When the resistance of a material to one form of stress has been found by experiment, its resistance to all other forms can be deduced by calculation.

The author's experiments have confirmed the truth of the first law. With regard to the second, they are not yet complete. They do not agree with the third, inasmuch as experiments on transverse strain showed a much greater tensile resistance in the most heavily strained fibre than that given by direct experiments on tearing. Again, on comparing experiments on Krupps's axle steel, made in 1863 by Wöhler, and in 1873 by the Author, it appears that in the interval the material had been greatly improved in its resistance to the ordinary stresses of axles, but had diminished in its resistance to direct tension.

This latter is, of course, no real defect, and is, no doubt, due to an alteration in chemical composition; but it shows that tensile tests alone will not indicate the character of a material, and also how necessary it is frequently to repeat such experiments.

The Author has further endeavored to investigate the connection between the appearance of fracture and the molecular changes, in pieces broken by repeated strains. His theory is that under such strains the texture of the metal is gradually changed from the crystalline to the amorphous. There thus arise different states of equal density of the molecules, each state having its own limit of elasticity. As the strains go on, these limits of elasticity are passed in the case of a continually increasing number of the molecules, and the piece is thus gradually weakened until rupture results. This he considers to accord with the molecular theory of Fourier and Redtenbacher, viz., that metals consist of crystalline molecules of attracting matter, each intermixed and surrounded with repelling ether. The action of strain would then be to break up the molecules into smaller and smaller elements. Hence is explained the fact that just at the point where rupture begins the fracture looks dull and amorphous (because the action has there been the most intense), while at a distance it is still crystalline. The rays, which are generally seen converging to this point of rupture, are due to a flow of surrounding molecules to the more heavily strained parts. In phosphor-bronze, broken by repeated strains, a flow of the phosphorus to the more extended parts is distinctly visible.—*Abstracts of Institution of Civil Engineers.*

RAILWAY NOTES.

We are informed that the directors of the Paris, Lyons and Mediterranean Railway Company, have decided to apply the Westinghouse brake over the whole of that immense system, and that a contract has been made with the Brake Company for the supply of the fittings for 1,500 vehicles as a first instalment. The cost of fitting the whole of the passenger engines and carriages will amount to about 8,000,000f. Our neighbors are settling the brake question in France in a much more business-like fashion than the authorities on our own railways, for the Westinghouse brake has now been adopted on lines having one-half —and by far the more important half—of the entire mileage of French railways, and as the Railway Commission is insisting upon what are virtually the conditions laid down by our own Board of Trade, there seems little doubt that the whole of France will be efficiently equipped long before our own railway magnates have done wrangling over the numerous inventions, both of their own and others, and which at present interfere with the settlement of the brake question in this country.

Breakages of Steel Rails on Russian Railways During 1879.—The statistical returns of the Russian Ministry of Ways and Communications give the following interesting information on the breakages of steel rails on Russian railways during 1879. Up to January 1, 1880, on all lines, the length of which amounted to 24,019 miles, 9,730 miles of steel rails had been laid. The total length of the Russian railways, taking in consideration station sidings, was in 1879, 19,200 miles, and the breakages of steel rails during that year were as follows:

Months.	Total No.	Months.	Total No.
January	639	July	247
February	598	August	156
March	854	September	214
April	235	October	328
May	235	November	341
June	160	December	692

The best rails, judging by the small quantity broken, were of English manufacture, namely, those from Messrs. Brown, Bayley & Dixon, Sir J. Brown & Co., Cammell & Co., and the Barrow Hematite Iron and Steel Company.

Writing on the manufacture of paper railway wheels, the *Paper World* says: "The paper is straw-board of rather fine texture. It is received in the ordinary broad sheets, differing in no particular from those used for straw board boxes or other similar work. These sheets as they come from the paper mill are square, and are first cut to a circular pattern. This is done on a table with a knife guided by a radial arm. A small disc is also cut from the center of the sheet to admit the wheel center. The paper has now to be converted from loose sheets into a compact, dense body, capable of withstanding the tremendous crushing force to which it will be

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subjected in the wheels. This is accomplished as follows: Ten sheets are pasted together, one upon another, making a disc about ½ in. thick. Enough of these discs having been prepared to fill a powerful hydraulic press, they are subjected to a pressure of 1800 lbs. per square inch. When removed, the discs are hung on poles in a steam-heated loft and left six days to dry. Thicker discs are then made, each formed by pasting together two or three of those already finished. These are pressed and dried as before, and the process is repeated until a block is built 4 in. thick and of about the specific gravity of lignum vitæ. After each pasting and pressing six days are allowed for drying, and when the block is complete it is left in a drying-room until thoroughly seasoned. The next operation is that of turning the paper blocks to fit the steel tires and iron centers. This is done in lathes in the same manner as if the material worked on was tough wood. A bed or recess is worked out for the web of the tire to rest in. The block is then painted, and is ready for its place in the wheel."

THE London, Chatham and Dover Railway Company has not, we believe, made any promising announcements as to new station accommodation. With the inclement weather which now prevails an ordinary dry station is not the most desirable place to shiver away a half hour, but on the barns of stations with which the passengers are provided by the Chatham and Dover Company, even near London, words will not do justice to the outraged feelings of some of their passengers. It is therefore no desirable thing that passengers should be made to wait unnecessarily on the platform of such places. The Chatham Company has, however, issued a regulation that the gate entrances to some platforms shall be closed as soon as certain trains are due. No objection whatever can be made to closing these gates when a train is in sight or even signaled, or at any time if notice is given that it will be done, but closing them when a train is due involves discomfort to passengers. At the stations where there are two or three departure platforms this is especially the case during bad weather when rails are in bad condition and all trains are or are liable to be more or less late, for a passenger goes on to a platform, say ust before a train is due. He finds that the train is not even signaled, and thinks he will be able to take a train signaled at another platform. He leaves the first platform and goes to the second only to find the gate closed. Finding this he goes back to the first platform only to find that though the train is, as he knows not even signaled, the gate is shut. This train is late, perhaps very late, and the passenger waits until it comes in and goes, which he may have the pleasure of seeing it do. Then he may wait for another train not yet due, so that if he has patience he has time to sit down—no he cannot sit down, because the seats not occupied by the other passenger, who sits in a mackintosh lost in a reverie on railway pleasures, may be wet; but he can stand and think of the great difference between the ordinary public mind and the mind that can master the mysterious reasons of railway sages. At a station with only one platform such arrangements would be worse. A passenger arrives at the usual time for a train, trains are late, and the last train has only just gone, the gate is closed because another train is due. The passenger therefore waits until that train comes in and is gone, and then waits, unless, after exhausting his stock of complimentary expressions, he goes and takes a cab, tramcar, or omnibus. This sort of thing would not be so bad if the company had some fine stations they wished passengers to look at, but with stations without sides and with sieves for roofs it's—well it is not nice.

ORDNANCE AND NAVAL.

ARRANGEMENTS FOR THE DEFENCE OF THE MOUTH OF THE WESER.—The armor-plated works for the defence of the mouth of the Weser will shortly be completed. One battery for nine 21 cwt. guns, and two forts containing 10 turrets, intended for 28 cwt. and 15 cwt. guns have already been constructed in accordance with the approved principles of the present day for coast defences. The armament of the above works will consist of 24 pieces.

The two new forts, situated one on the right and the other on the left bank of the Weser, are built on a sand bank. They are washed by the river at high tide, and are surrounded by inaccessible ground at low tide.

The fort on the left bank is armed with lighter turrets than the one on the right, and has arrangements for these being worked by hand. Ten men can cause a complete rotation of the turret, weighing 492 tons, in five or six minutes. However, by means of a special contrivance two men will suffice to bring this about. The guns, mounted on carriages for *minima* embrasures, are worked by hand power, and can be served quickly enough to fire a round in a minute and a quarter.

There is a steam engine (the *Allgemeine Zeitung* states that this engine is an hydraulic one) in the fort on the right bank, which can cause the three turrets, weighing 590 tons, to revolve simultaneously and give 17° elevation to the six guns in them.

The chill cast armor plates which protect the fortifications at the mouth of the Weser have an aggregate weight of 7,529 tons, they were supplied by the Gruson foundry, which has also arranged the sub-structures of the turrets, and provided the ammunition lifts and the carriages for the *minima* embrasure. These armor-plated structures have one great advantage over those hitherto constructed in Europe. Thus, if a piece is struck and rendered unserviceable by an enemy's projectiles in English, Belgian, or other turrets, it has to be left in position till the end of the action, and you are deprived of its fire. In the Weser turrets, on the contrary, a certain apparatus allows the injured piece to be rapidly removed and immediately replaced by another which will continue the fire. Before being consigned to the mill-

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tary authorities the forts will be subjected to experiments intended especially to test the armored turrets and the guns.

Remarkable practice has already been made with the 28 cwt. guns. Although the maximum charge of 58 kilos. of prismatic powder was employed, the precautions taken at first to fire by electricity and remove the detachments from the turret were soon found to be superfluous. In fact, thanks to the small size of the embrasure, which is just large enough to allow of the passage of the muzzle of the gun, the powder gases cannot enter the turret, and are consequently not offensive to the gun detachments.—*Allgemeine Militar Zeitung and Neue Frankfurter Presse.*

RUSSIAN COMPOSITE 8-IN. SIEGE GUN, CAST (IN STEEL) AT THE FACTORY OF OBOUKHOFF.—The gun consists of:

1. An inner tube of steel (3.8 m.) containing rifling and chambers.

An envelope consisting of two parts:

2. One the breech and trunnions.
3. The other the muzzle part.

The first of these two travels on the siege carriage, and is united to the other by a ring screw collar.

There are two other small pieces.

The weights of the five pieces are as follows:

1. Inner tube	541
2. Breech	2904
3. Muzzle	1826
4. Screw Collar	98
5. Breech piece	299
Total	5668 kilos.

The interior tube is carried in a stiff-covered box.

The gun was put together and placed at Globosia, opposite Rustchuk, in three hours, after dark, by a detachment of 20 untrained men.

The piece had been previously fired 130 times with 7.8 kilos. of prismatic powder.

Seven shots were fired on the 25th of August, 1877, at 2,900 metres, at an earth battery; one piece said to have been dismounted.*

Six shots were fired at a gunboat on the 1st of September, one of which is said to have hit it.

On the 14th, 16th, and 19th November, 47 shots were fired at 4,900 yards against boats.

The gun stood together for three months, and was then taken to pieces with ease.

The Russians also made a 4-pr. mountain gun in three pieces of 98, 114 and 164 kilos. respectively.

BOOK NOTICES.

PUBLICATIONS RECEIVED.

THE TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS, containing:

"The Determination of Sulphur," by Thos. M. Drown, M.D.

"The American Bloomary Process," by T. Eggleston, Ph. D.

"The Eighty-Ton Steam Hammer at Creusot," by J. A. Herrick, M. E.

"The Weight, Fall and Speed of Stamps," by H. S. Monroe, Ph. D.

"Rail Specifications and Rail Inspection in Europe," by C. P. Sandberg, C. E.

"Cost of Milling Silver Ores in Utah and Nevada," by R. P. Rothwell, M. E.

"Chemical Reactions in the Bessemer Process," by Chas. F. King.

THE MONTHLY REPORT OF THE WEATHER BUREAU for November.

MODERN ARCHITECTURAL DESIGNS AND DETAILS, No. 4. New York: Bicknell & Comstock.

AMERICAN JOURNAL OF MATHEMATICS, Vol. 3, No. 2.

OFFICIAL GAZETTE OF THE UNITED STATES PATENT OFFICE, Vol. 19, No. 2.

NAVAL ENCYCLOPÆDIA.—Philadelphia: L. R. Hamersly & Co.

The Naval Encyclopædia is now complete. It is a royal octavo of 1170 pages.

This work has been prepared at a very large cost of time and labor, making it probably the most costly work ever prepared for the naval profession in this country.

The following summary of contents of the book will give an idea of its character and value:

I. A complete Dictionary of Nautical Terms and Phrases.

II. Biographical Notices of Distinguished Naval Officers of our own and foreign services.

III. Special Articles, including in their scope the entire range of Modern Naval Science, prepared expressly for this work by officers and others of recognized ability in their respective fields of discussion, and comprehending the freshest and most authentic information attainable respecting the several subjects treated.

IV. A Gazetteer of the principal Naval Stations and Seaports of the World.

V. A Supplement containing concise Records of Living Officers of the Navy, including Captains, Commanders, Lieutenant-Commanders and Lieutenants, and Staff Officers of relative rank. The records of Flag Officers are included in the body of the work.

Of the value to the service and nautical men generally there can be no manner of doubt. The publishers look confidently for a generous response to this, their final circular, from the officers of the service whom the book is primarily intended to benefit.

STEAM BOILERS: THEIR DESIGN, CONSTRUCTION AND MANAGEMENT. By WILLIAM H. SHOCK, Engineer-in-Chief and Chief of the Bureau of Steam Engineering, United States Navy. D. Van Nostrand, No. 23 Warren street, New York.

*I think this is a mistake: some of the 8-in. shells lay unburst in the town in September, but I heard nothing of a dismounted gun, and I think I should have had there been one.

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We may say at the outset that this handsome quarto reflects great credit on the printers and engravers concerned in its production. It contains thirty-six full page and double page finely-engraved plates, which are placed at the end of the volume, and 150 cuts inserted in the text. It is printed on fine calendered paper, and is altogether a triumph of American typography. The text is divided into nineteen chapters, whose headings alnoe indicate its scope, and the manner in which the various divisions of the subject are treated fairly entitle the author to say, as he does in the preface, that he has "supplied a long felt need in this particular branch of engineering and construction." His short introductory chapter tells us of the materials used in the construction of boilers in the earlier days of the steam engine, why copper was superseded by plate iron, the latest forms of boilers due to the introduction of compound and high steam pressure, the essential parts of a steam boiler, how infinitely forms may vary, the conditions which determine the features of marine boilers, and particularly those affecting boilers in war steamers. The general subject thus stated, he takes up "combustion" in a chapter which gives us the latest chemical knowledge of fuels and their constituents, the latest data on temperatures of ignition and the total heat of combustion. Taking in, as it does, all the facts relating to fuel as a source of power, it necessarily gives, with all the precision attainable, the figures for calculating the important elements of furnace draughts. He now proceeds to examine the "transmission of heat and evaporation," a most important consideration, for on the efficiency of the heating surfaces depends the rate of steam production, and so leads up to the latest direction which inventiveness in steam engineering is taking—namely, the use of superheated steam. Its economy of fuel is undoubted, and the only other question to be answered is that of "the bulk, weight and cost of the superheating apparatus or the labor and expense of keeping it in working order and its liability to derangement." The chapters on "Materials" is interesting even to the lay reader, who takes the slightest interest in metallurgy. The use of copper, brass, the invaluable phosphor-bronze, cast iron, wrought iron and latterly steel, which improved processes of manufacture have made available, is treated historically and scientifically, invaluable tables of weights of iron used for plates and rivets being appended. The chapter on "Testing the Material" and "Principles of the Strength of Boilers" involve matters of great moment to the profession, and not less to the public. We now come to the making of the boiler, and this is exhaustively considered in ten chapters, which take the engineer from the design on paper to the boiler set up and ready for its final tests. As indicating the minuteness of the details given we may say that these ten chapters on construction are divided into eighty-eight sections, which include a mass of tabulated data and mathematical formulas. "Tests, inspections and trial of steam boilers" is a chapter which again has grave interest ontside of engineering circles, for on the faithfulness and efficiency of the test life no less than property is almost always dependent. The difficulties in the way of a thorough test are often very great. There is, therefore, grave significance in the author's words:

"Boilers which are faulty in design or built of inferior material, or have had workmanship put on them, may stand the hydraulic test, but under the varying and continued strains of actual practice they will, sooner or later, develop weaknesses which seriously impair their life and safety. Grave defects may be hidden from view after a boiler is built so that they cannot be discovered by the closest scrutiny. Therefore, the inspection of boilers should commence with the process of construction, and should be repeated frequently during the lifetime of the boiler."

The tricks resorted to by boiler makers, such as punching the rivet holes too close to the edge of the plates when these happen to be cut too small, are here pointed out. The various kinds of tests and their relative values are minutely examined. "Management of Boilers" takes the engineer skillfully through this important portion of his duties and leads naturally to the consideration of "Causes and prevention of the deterioration of boilers." In general the deterioration arises from the accumulation of scale or sediment, from corrosion, fracture, burning or distortion of plates. These are generally traceable to defects of design, material or workmanship; to mismanagement, the use of sulphurous fuel or impure water and to galvanic action. In addition to this formidable catalogue the author says: "There are some destructive agencies at work shortening the life of boilers, the action of which is not fully understood; and instances of the rapid deterioration of boilers occur, from time to time, for which no definite cause can be assigned." Stationary boilers frequently last twenty years; the life of marine boilers ranges, under favorable conditions, from nine to twelve years, and in naval vessels is often limited to six years of use. The varying conditions of prolonged strain and protracted idleness, of frequent impossibility during long cruises on distant stations of regular cleaning and repairs, account for the shorter life of the war steamer's boiler. The closing chapter is devoted to a subject ugly in itself, but as it is one of the means by which the life of the boiler is determined, must have a place—namely, "Boiler Explosions:"

"It is," says the author, "of the gravest importance that the true causes of every boiler explosion should be clearly understood in order that their recurrence may be guarded against. The tendency to ascribe explosions to obscure causes rather than to regard them as the natural results of conditions which can be prevented by intelligent care exercised in the design, construction and management of boilers, has, no doubt, its origin in the desire to escape responsibility for the results of culpable neglect, and has been productive of much mischief by engendering carelessness on the part of owners and attendants of steam boilers."

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It is not sufficient to show that a certain set of circumstances could exist in a case of explosion, but that they actually did exist. Several of the extravagant theories, such as sudden development of electricity, the formation and detonation of hydrogen and oxygen, the constituent gases of water, the instantaneous conversion into steam of large masses of water, and so on, are satisfactorily met and disposed of. Apart from external injury or violent concussion the explosion of boilers are generally traceable to undetected or unremedied defects in construction, or ignorance or carelessness of management, either in the boiler itself or the furnace chamber and fuel supply. We cannot follow this part of the subject further, but it has a vital interest that recommends it to the consideration of every person concerned in the ownership and management of boilers. We have, indeed, barely skimmed the work in giving our testimony to its great value and the labor and knowledge it represents. These only can be estimated by reading it carefully from cover to cover and knowing how far it distances any work of the kind which pretends to give information on the subject up to the requirements of the present day.—*N. Y. Herald.*

MISCELLANEOUS.

HERR VON BOGUSLAWSKI has been led, from a comparison of the results of recent deep sea investigations, to the following conclusions respecting the temperatures of the Atlantic and Pacific Oceans: 1. The water of the North Pacific is, in its whole mass, colder than that of the North Atlantic. 2. The water of the South Pacific is, down to 1300 meters—4225ft.—somewhat warmer than that of the Atlantic, but below the depth colder. 3. The bottom temperatures are generally lower in the Pacific than the Atlantic at the same depths and in the same degree of latitude; but nowhere in the Pacific are found such low bottom temperatures as in the Antarctic portion of the South Atlantic between 36 deg. and 38 deg. south and 48 deg. and 33 deg. west longitude, in which bottom temperatures of —0.3 deg. C. to —0.6 deg. C. have been measured. 4. In the western parts of the Pacific, and the adjoining parts of the East Indian Archipelago, the temperature of the water reaches its minimum at depths between 550 and 2750 meters—1787 ft. and 8937ft.—remaining the same from this depth to the bottom. In the whole of the Atlantic the temperature from 2750 meters—8937ft.—to the bottom gradually though very slowly decreases.

SOLIDIFICATION UNDER PRESSURE.—Walther Spring has investigated the phenomena of universal regelation, or, in other words, the property which the particles of solid bodies possess of uniting by cohesive action under pressure. The pressure in some of his experiments exceeded 20,000 atmospheres, but in the majority of cases from 2,000 to 3,000 atmospheres were sufficient to secure his results. He concludes that all solid bodies possess the property of uniting when they are in close contact. This property is more or less pronounced in different bodies, and it appears to be a function of the hardness. Soft bodies are easily soldered; hard bodies, with difficulty. There is, however, another element which influences the union, to which he gives the name of waxiness, and which is illustrated by Tresca's experiments upon the flow of solids. In every case the bodies which were submitted to pressure were changed into a denser variety; prismatic sulphur, for example, which has a specific weight of 1.96, was changed into octahedric sulphur, with a specific weight of 2.05. We may infer from this fact that the state which matter assumes depends somewhat upon the volume which it is obliged to occupy, through the action of external forces. These experiments seem calculated to throw new light upon some important geological questions; the layers of primary rocks, for example, may have resulted from the union of the grains of sand or mud which were borne along by the waters; the great pressure would have ground and thrust and broken and soldered them anew so as to give them the form which they now possess; faults and cleavages of every description would be comparable to the crevices of glaciers.—*Bull de l' Acad. Roy. de Belg.*

THE towers of Cologne Cathedral are now the highest in the world, the height they have attained being 5ft. higher than the tower of St. Nicholas Church in Hamburg, which has hitherto been the highest edifice. When finished they will be 51ft. 10in. higher. The *Cologne Gazette* gives the following as the heights of the chief high buildings in the world: Towers of Cologne Cathedral 524ft. 11in. from the pavement of the cloisters, or 515ft. 1in. from the floor of the church; tower of St. Nicholas, at Hamburg, 473ft. 1in.; cupola of St. Peters, Rome, 469ft. 2in.; cathedral spire at Strasburg, 465ft. 11 in.; Pyramid of Cheops, 449ft. 5in.; tower of St. Stephen's, Vienna, 443ft. 10in.; tower of St. Martin's, Landshut, 434ft. 8in.; cathedral spire of Freibourg, 410ft. 1in.; cathedral of Antwerp, 404ft. 10in.; cathedral of Florence, 390ft. 5in.; St. Paul's, London, 365ft. 1in.; ridge tiles of Cologne Cathedral, 360ft. 3in.; cathedral tower at Madgeburg, 339ft. 11in.; tower of the new Votive Church at Vienna, 314ft. 11in.; tower of the fine new brick-built Rath-haus at Berlin, 288ft. 8in.; towers of Notre Dame at Paris, 232ft. 11in.

THE death is announced of Mr. William Lassel, F. R. S., on the 5th inst., in his eighty-second year. He was an astronomer of unusual ability, and the inventor and constructor of astronomical apparatus of great importance. His attainments in astronomy and physics and mechanics enabled him to discern the requirements of the observer, and to comprehend and apply the conditions and principles involved in the construction of the things required.

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VAN NOSTRAND'S

ENGINEERING MAGAZINE,

COMMENCED JANUARY, 1869,

Published on the 15th of the month at $5.00 per year.

The January number of this MAGAZINE, for the year 1881, begins the Twenty-fourth Volume. Beginning as an Eclectic Journal, and presenting almost exclusively matter selected from current literature, it has gradually become the chief medium through which the leading writers on engineering subjects can best present their original essays to American readers.

The attitude of the MAGAZINE has been, and will continue to be, that of a journal of original and selected papers upon subjects relating to modern advanced Engineering. Theoretical and Practical Essays are alike presented in its pages, although the latter largely out-number the former, as best suited to the tastes and demands of the American Engineers. Some of the most valuable contributions to the literature of technical science within the last few years have been first presented in these pages.

Among the more extended original contributions to the later volumes may be cited new contributions to Graphical Statics—Transmission of Power by Wire Ropes—Maximum Stresses in Framed Bridges—Momentum and Vis Viva—Rapid Methods of Laying out Gearing—Transmission of Power by Compressed Air—Geographical Surveying—Mathematical Theory of Fluid Motion—Thermodynamics—Practical Theory of Voussoir Arches—Cable Making for Suspension Bridges, &c., &c.

To the above may be added the following valuable essays, translated from foreign sources, which have first appeared in these pages: Linkages and their Applications—The Origin of Metallurgy—and The Theory of Ice Machines.

The plans for future volumes comprehend many improvements in the same direction. The wants of the educated practical engineer, who desires to keep in the foremost rank of his profession will be steadily kept in view, and our constantly increasing resources for supplying the best of scientific information will be employed to secure such result.

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VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CXLVII.—MARCH, 1881.—VOL. XXIV.

THE PRINCIPLES INVOLVED IN THE CONSTRUCTION OF THE TELESCOPE.

By THOMAS NOLAN, B. S.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

III.

(4.) DOUBLE REFLECTION.

When the curvatures of the inner surfaces of the glasses of an achromatic lens are such that they exactly fit each other, they are frequently joined together with a transparent balsam, so as to diminish the loss of light in passing through the lens. Whenever light falls upon transparent glass, between 3 and 4 per cent. of it is "reflected back," and when, after passing through, it leaves again, about the same amount is "reflected back" into the glass. Consequently, about 7 per cent. of the light is lost in passing through each lens. By joining them with castor-oil or balsam, the reflection from the second surface of the flint, and the first surface of the crown is very much diminished, and the loss of about 6 per cent. of the light is avoided. In case there is no balsam, the inconvenience of *double reflection* arises. Some of the light "reflected back" from the second surface of the flint, is again reflected from the first surface of the crown, and sent down to the focus of the telescope with the direct rays. If one of the lenses be displaced in the slightest degree, the reflected rays will come to a different focus than the direct ones, and every bright star, for instance, which is viewed with the instrument, will seem to have a small companion star along-side of it.

2. THE EYE-PIECE.

We have thus far discussed the optical principles which are applied in the construction of refracting and reflecting telescopes, consisting of an object-glass or speculum and an eye-piece of the simplest form, viz: a single double-convex lens. We will now go into detail somewhat on the subject of eye-pieces, and explain some of the different kinds.

Every ordinary lens possesses the disadvantages of both chromatic and spherical aberration, which have been discussed in connection with the objective. But the eye-piece is not corrected for these errors, in the same way that the objective is. In the case of the former, the errors are corrected by using two lenses of such focal lengths, or at such a distance apart, that each counteracts the defects of the other. We do not use two kinds of glass as in the case of the objective, but so arrange the lenses, that the colored rays produced by the first lens shall fall at different angles of inci-

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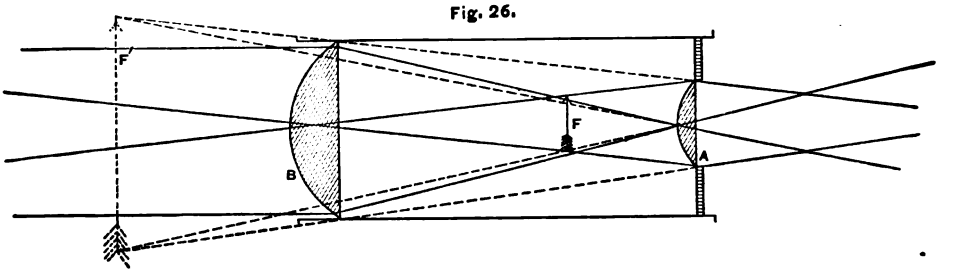
dence on the second, and thus become recombined.

(1.) THE HUYGHENIAN EYE-PIECE.

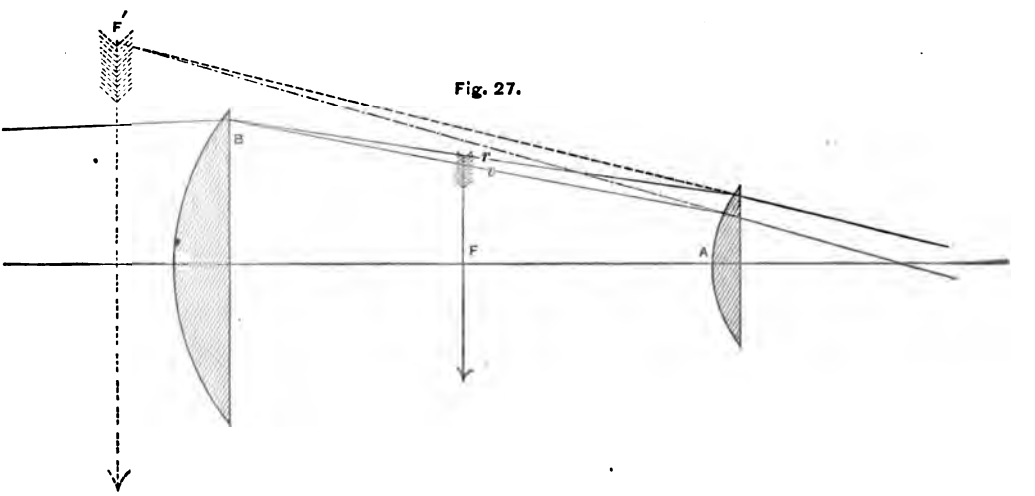
This eye-piece consists of two plano-convex lenses A and B (Fig. 26), with

Fig. 26.



their convexities turned towards the object-glass, and having their focal lengths in the proportion of 3 to 1. The strongest lens, A, is next the eye, and B is placed inside the focus of the object-glass and brings the image to a

Fig. 27.



focus at F, about halfway between A and B. This image is then viewed by A, and a magnified image of it is seen at F′. To show how this combination is achromatic, let us consider the path of a ray falling on the lens near B (Fig. 27). It is there refracted, but as the violet rays are refracted more than the red, there are two rays produced, r and v, giving a colored edge to the image. But when this image is viewed by A, it no longer appears colored, for v, falling nearer the axis of A, is less bent than r, and they are rendered nearly parallel and appear to proceed from the point F′, where the image appears without color. The focal length of B is three times that of A, and they are placed at a distance of half their joint focal length apart.

(2.) THE RAMSDEN EYE-PIECE.

The Ramsden eye-piece consists of two

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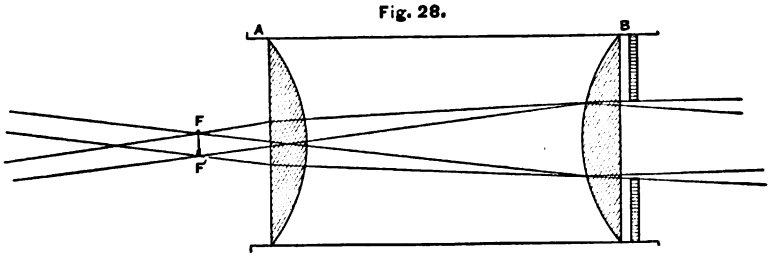
plano-convex lenses, A and B (Fig. 28), of the same focus, placed at a distance of two-thirds the focal length of either apart. They are both on the eye side of the focus of the object-glass, and act together to render the rays parallel, and give a magnified virtual image of FF'. This eye-piece is not strictly achromatic,

Other forms of eye-pieces might be mentioned, as the *Pancratic Eye-piece*, the different forms of *Solar Eye-pieces*, etc., but the various forms, which have been described, are sufficient to illustrate the general principles involved in the construction of those most commonly used for astronomical investigations.

Fig. 28.



but suffers least of all from spherical aberration, and has the advantage of being placed behind the focus of the object-glass, which makes it superior to others in instruments of precision.

(3.) THE ERECTING, OR DAY EYE-PIECE.

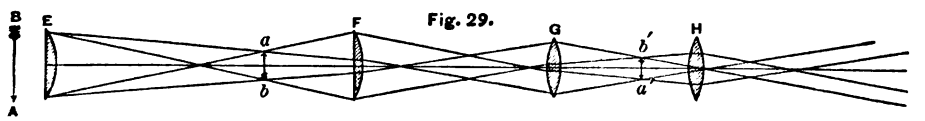
The eye-pieces, which we have described, give an inverted image of the object, that is, they do not right again the inverted image formed by the object-glass. Fig. 29 is a diagram of an erecting eye-piece due to Rheita, and called by his name. It is merely a second application of the same means that first inverts the object AB, viz; a second small telescope. Dolland substituted an Huyghenian eye-piece for the eye-lens H, and so made what is called "Dolland's Four Glass Eye-piece."

IV. COMPARISON OF REFRACTING AND REFLECTING TELESCOPES.

A word or two remains to be said in regard to the relative advantages and disadvantages of the two classes of instruments. The question arises, To which class will the great telescope of the future probably belong? Will it be a refractor or a reflector? In treating of the question of the future of the telescope, many authors have encroached upon the domain of opinion, and have gone beyond the facts vouched for by evidence. But in a discussion of this kind there are three questions to be borne in mind. Of the two classes of instruments:

1. Which has the greater "*light-grasping*" *power?*

Fig. 29.



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2. Which is more generally *suitable for observatory work?*

3. Which has greater *permanence of optical qualities?*

In regard to the *first question*, it is certain that up to the present limit of size produced, the refractor has the advantage. But in the reflector, the reflecting power of each unit of surface is constant, whatever the size of the speculum, and in the refractor the transmitting power decreases with the thickness of the glass, rendered necessary by increasing size. It is obvious then, that on increasing the size, a stage must be at last reached, when the two become equal to each other. The limit has been estimated to be 35.435 inches, a size not yet reached by about 9 inches. But object-glasses are slowly gaining in size, and it is not improbable that this limit will sometime be reached.

Suitability for observatory work, depends somewhat upon the nature of the work required. For measuring positions, where permanency of mounting is of great importance, the refractor has decidedly the advantage, whereas, for physical astronomy, where a steady image for a time only is required, it may be found that the advantage will be on the side of the future great reflector.

The *question of permanence of optical qualities* is worthy of attention, and here again, the refractor undoubtedly has the advantage. It is very rarely the case that the polish of object-glasses is in any way injured even after many years of continuous use; while specula, whether of metal or of silvered glass, become considerably tarnished after a few years of service.

After considering these advantages and disadvantages of the two classes of telescopes, we are led to the following conclusions:

1. At the present day the largest refractor is equal in optical power to the largest reflector. It is more convenient in use, easier to manage, and better adapted to general observatory work. And it enjoys a greater permanence of optical qualities.

2. The reflector will be the great telescope of the future if, (1) specula of large diameter can be produced, free from imperfections of curvature and polish; and if, (2) increasing difficulties of mounting and manipulation can be overcome. If these latter mechanical difficulties cannot be entirely removed, the refractor will continue to be the "working instrument" in the future, as it has been in the past, although the future reflector may accomplish the grandest results in the domain of Physical Astronomy.

ON THE EMPLOYMENT OF TORPEDO BOATS AGAINST SHIPS.

By LIEUTENANT CHABAND ARNAULT.

Translated from the "Révue Maritime et Coloniale."

At the end of an article published in the *Révue*, for May, 1874, entitled, "Heavy Guns, Armor Plating and the Ram, in Naval Engagements," we wrote the following lines: "We leave aside the torpedo, because it has never yet figured in engagements between ships, and we wish to argue, not on the results of experiments, more or less conclusive, made in time of peace, but solely on the results of war during the last ten or fifteen years." The Turco-Russian War, which has just been concluded, has given us now the means of applying a similar process to the study of torpedo warfare, employed, not, it is true, as a weapon by sea-going ships, but simply as an engine of destruction used by small steamboats. Relying on the Russian reports M. le Commandant Chardonneau has published, in the *Révue*, very interesting accounts of the principal naval actions fought by the boat-torpedoists of the Czar's fleet. It is a matter of great regret that we are unable to study the account of the same occurrences in the official reports

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addressed to the Turkish Government.* We have, however, obtained some information from the latter source, which we shall not fail to make use of. Besides these, the Civil War in America offers two or three naval engagements in which torpedo boats played an important part; we give the particulars of these, before describing those to which the Turko-Russian War gave rise.

Our work is thus divided into two parts: the first consists of the recital of the bare facts useful for us to know; in the second we shall endeavor to throw some light on the lessons which may be drawn from them.

I.

(I.) The destruction of the "Houssatonic," on the night of the 17th February, 1864. In the course of the year, 1863, the Confederates built several boats, taking more or less the cigar form, and known in America by the name of "Davids." These boats were intended to attack the Federal vessels with spar torpedoes. One of them, built at Charleston, had the power of sinking herself completely at the moment of attack. Her propeller was a screw, worked by hand, by a crew of eight men. During her first cruize, under the orders of Lieutenant Payne, an enemy's vessel passed close to her without noticing her; the swell raised by the paddles of this craft sank the "David," and Payne alone, of all the crew, saved himself. This intrepid officer did not lose heart, and he persuaded eight sailors to follow him again in his boat when she was recovered. A squall of wind produced an accident similar to the former one. Payne and two blue jackets escaped death. The boat, again picked up, had some novel experiences. At the intended moment she dived, but never came up again, and Payne perished this time with all his crew. And even after three such catastrophes, a Lieutenant Dixon was able to find eight men sufficiently devoted to man the same boat when she was fished up from the bottom of the River Cooper!

"On the 17th February," writes the author of several interesting remarks on the Civil War, "the Federal corvette "Houssatonic" was at anchor off Charleston, on the outer line of the blockade; it was dark when, about 8.45 P. M., the officer of the watch perceived something moving in the water towards the ship, about 100 yards distant. It came straight towards the ship, and in two minutes was alongside. During this time the cable was slipped, the engines moved astern, and the crew called to quarters. About one minute later the explosion took place, and the ship, going down by the stern, heeled over to port, and sank. Happily the weather was fine and the water shallow. The crew, with the exception of two officers and some men who were drowned, saved themselves in the rigging, and were rescued by the boats of the 'Canandaigua.'"

It was the heroic Dixon who thus inaugurated, in naval engagements, the *role* of the torpedo carried at the end of a spar. His submarine boat disappeared with all its crew.

(II.) Unsuccessful night attack on some Federal frigates. "Other unsuccessful efforts," continues the author whom we have already quoted, "were made by the Confederates against the men-of-war of the Union. The first was directed against the ironclad frigate 'New Ironsides,' by a rebel Lieutenant, who, in a small cigar-shaped boat, proceeded to attack her in the middle of the night, when off Charleston. Although he got alongside without being discovered, and although the explosion was effected, there was no further damage done than the death of the officer of the watch of the 'Ironsides,' and the loss of the torpedo boat, which was sunk by the mass of water thrown up by herself. The frigates 'Minnesota,' 'Wabash' and 'Memphis,' were successively attacked by cigar-shaped torpedo boats, but they escaped, owing to the watchfulness of those on board."

(III.) Destruction of the "Albemarle" (night of the 27th October, 1864).—Towards the close of the year 1864, the town of Plymouth, on the River Roanoke, was in possession of the Confederates, but besieged by the Federal troops. A Confederate ram, the "Albemarle," defended it against all attacks from the river side. This vessel was se-

* Though no official Turkish reports have been published, Hobart Pasha, commanding the Turkish Fleet in the Black Sea, has printed in vol. cxxvii. of the *North American Review*, 1878, some notes on the occurrence in the late war. His statements differ very much from the Russian accounts.—Ed.

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cured to a quay, under the double protection of a battery of guns and a stockade of floating branches of timber, which formed a circle about ten yards from her. A young officer of the Federal navy, Lieutenant Cushing, volunteered to attempt the destruction of the "Albemarle" by means of a boat fitted with a spar torpedo. On the night of the 27th October, he ascended the Roanoke, and was received, on approaching the ram, by a brisk fire of musketry; his boat, however, going at full speed, struck on the stockade. Cushing himself worked the movable spar of his torpedo, placed it beneath the side of the "Albemarle," and fired it by means of a friction tube. The explosion, or perhaps a shot from the ram, sank the Federal boat, but the "Albemarle" went down almost immediately, and Lieutenant Cushing, who saved himself by swimming, succeeded in rejoining the Federal army through the woods.

Such were the several very noteworthy engagements which gave rise, during the American war, to the employment of torpedoes as offensive weapons by boats. We shall now recount the similar acts which signalized the last war between Russia and Turkey.

At the commencement of hostilities the Turks had, on the Danube, 3 monitors, 5 ironclad gunboats, and 6 wooden gunboats; in the Black Sea, 2 frigates and 8 ironclad corvettes, besides a certain number of wooden ships. The Russians could oppose no respectable man-of-war to this numerous fleet, but they possessed, in the Black Sea ports, 15 torpedo boats, mostly of the Thorneycroft type, with silent engines, very light and fast, and built in water-tight compartments. A screw-steamer, the "Constantin," handed over to the Government by a maritime Company of Odessa, was arranged to carry, and to hoist up rapidly under massive boomkins, four of these boats. The Russians also launched on the Danube quite a flotilla of torpedo boats, but the majority of these latter were ordinary steam launches fitted with a spar torpedo over the bows.

(IV.) First affair of Batoum (night of 12th May, 1877).—At ten o'clock in the evening, the "Constantin" being seven miles from Batoum lowered her four boats, which immediately steered for the port. On arriving there, the "Tchesme," commanded by Lieutenaut Zatzarennyi, was ahead of the other Russian boats by three or four cables' lengths; he was armed with a towing torpedo. Zatzarennyi, observing an ironclad moored at the head of the bay, cleverly manœuvred his boat and succeeded in striking with his torpedo the stern of the vessel. No explosion occurred. We do not know the exact type of the "diverging" torpedo employed by the Russians, but it appears that the towing conducting wire, which was fouled for a moment in the screw of the "Tchesme," suffered a denudation, which prevented the electric current from passing and from lighting the primer. The Turks, however, had taken the alarm, their shore batteries, as well as their ships, opened such a brisk fire of artillery and musketry, that the torpedo boats thought it best to be off with all speed. The "Tchesme" and the "Sinope" reached the neighboring harbor of Poti, the other two boats rejoining the "Constantin."

(V.) Destruction of the "Seife" (night of the 25th May, 1877).—Three Turkish ships were at anchor, with steam up, in the arm of the Danube which passes the town of Matchin, the double-turreted monitor "Seife," an ironclad gunboat, and a wooden ship. No obstructions protected them, but two guard-boats watched them, one at a short distance from the "Seife," the other near the ironclad gunboat. Four Russian torpedo boats, from the neighboring town of Braila, steamed up the Matchin arm to attack the Ottoman squadron. They were ordinary steam launches, whose engines and crew, composed of about a dozen sailors, were protected, with the exception of the man at the tiller, by metallic roofing; each of them being armed with a torpedo carried at the bow, containing a large charge of gunpowder and which could be immersed to a depth of 10 feet, and fired electrically either by contact or by will. The sky was overcast, a slight mist hung about the river, but the night was not very dark. The Russian boats crept along the banks of the river, and as their engines were noisy, they went slowly so as to make as little noise as possible. The Turkish officer, who commanded the "Seife's" boat, perceived them, but lost his head, and

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pulled off as fast as possible instead of alarming his compatriots. It was then half-past two in the morning. Arrived within a cable's length of the "Seife," Lieutenant Doubaroff, who commanded the Russian boats, put his boat, the "Czarwitch," at full speed, and was hailed and made out by the Turkish sentries. His torpedo struck the keel of the "Seife" under the overhanging part of the stern and exploded by contact. The "Czarwitch," which the fall of water had three-quarters filled, hauled off as quickly as possible under the fire of musketry from the monitor. The latter began to sink astern, but so slowly that at the end of ten minutes Doubaroff ordered the "Xenia" to attack her. Lieutenant Chestakoff, who commanded this boat, took the "Seife" broadside on, and exploded his torpedo by hand. He experienced some difficulty in getting away, as the screw of the "Xenia" was fouled by some of the *debris* arising from the two explosions. Happily the "Seife," which had only been able to fire two shots, then sank very rapidly until the moment of her disappearance, her brave crew never ceasing to keep up the fire from theirrifles. The other two Turkish ships, slipping their cables, had opened a well-sustained fire of artillery and rifles. A bullet pierced the hull of one of the two boats which had been left in reserve. This boat was obliged to beach herself on the bank, but quickly stopped the leak, and was able to follow the other boats of Doubaroff in their retreat. This fine affair cost the Russians none killed nor wounded.

(VI.) Affair of Sulina (night of 10th June, 1877).—In consequence of the feeling caused by the loss of the "Seife," the Commander-in-Chief of the Turkish fleet, Hobart Pasha, ordered the vessels under his command to observe the following rules: 1st. To keep one watch under arms at their quarters all night. 2d. To constantly patrol, by boats under steam, or, in default of these, by boats under oars, the neighborhood of the vessel. 3rd. To surround the latter by obstacles capable of stopping the advance of a torpedo boat. All these measures of prudence were rigorously observed by the crews of three armored corvettes and a gunboat at anchor before Sulina on the night of the 10th June. The obstacles which surrounded these vessels consisted of ropes, arranged parallel to each other like clothes-lines, stretched between two boats which were kept in their places by strong anchors, and supported at intervals by little buoys, the upper part of this system coming level with the top of the water, though keeping out of sight. The Russians affirm that one of the Turkish ships was under weigh, but the Turks do not mention this circumstance. The ironclad corvette "Idjalick" was anchored at the head of the squadron.

The "Constantin" had left Odessa on the 10th June, with three torpedo boats hoisted to her davits, and three more in tow, and stopped the following night when five miles from Sulina. At half past one in the morning, the boats, divided into two groups, steered towards the port. At their head was the "Tchesme," commanded by Zatzarennyi, and armed with a "diverging" torpedo; their boats Nos. 1 and 2, under the orders of Lieutenants Poustchine and Rojdestoonski. The night was so dark that in spite of the precautions taken by the Turks, the Russian boats arrived within 100 yards of their ships without being observed. Zatzarennyi made a sweep to bring his "diverging" torpedo to bear against the "Idjalick," but his towing-conducting wires fouled the screw of the "Tchesme," and she was obliged from that time to cease taking part in the action.

According to the account of M. Chardonneau, the torpedo boat No. 2 attacked the "Idjalick," whilst No. 1 advanced on another vessel, but all the accounts from Turkish sources agree in pointing out the "Idjalick" as having been the adversary of Lieutenant Poustchine, and besides, none of them say that any other ship had to repulse a Russian attack. It is, therefore, nearly certain that the "Idjalick" was the only antagonist of boats Nos. 1 and 2. The latter, going at full speed, cleared the obstacle round the Turkish ship, and her torpedo exploded on contact; it is probable that it struck some obstacle before touching the bottom of the "Idjalick," or was struck by a projectile which ignited its priming, since this explosion produced no damage to the enemy's ship. The Turks, in their reports, do not even mention it. How-

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ever it may have been caused, the water from it filled the fore compartment of boat No. 2, and she, being thus brought down by the head, was able to clear the obstacles and free herself by going astern. For some minutes the Turks had opened a general fire of artillery and musketry, it was then that No. 1, stopped at first by the ropes of the obstruction, succeeded in clearing it. Lieutenant Poustchine was standing by to fire the torpedo himself if contact did not effect it, but the explosion took place in an unexpected manner before the boat's spar touched the enemy's bottom. The "Idjalick" only suffered some slight damages above water. It appeared that, excited by the brisk fire of the Turks, the blue jacket charged with immersing the torpedo had failed in his work; the torpedo was on the surface of the water and was struck by a projectile which exploded it. Lieutenant Poustchine disengaged himself, but his boat had suffered such damages that they were obliged to abandon her, and this brave officer and the six men who accompanied him were kept afloat by their life-belts; at daybreak they were picked up by the Turkish boats.

The second group of Russian torpedo-boats, who had taken no part in the action, the "Tchesme" and No. 2, rejoined the "Constantin," without the loss of a man.

(VII.) Day affair near Rustchuk (20th June, 1877).—With the intention of closing the navigation of the Danube to the Turkish ships, the Russians had adopted the plan of placing lines of mines in several places. On the morning of 20th June, six of their boats were occupied in arranging such an obstacle, near Rustchuk, when a Turkish ironclad from this place obliged them to take refuge amongst the reeds which border the river. The boat "Choutka," armed with a spar torpedo, and commanded by Lieutenant Skrydloff, started at full speed to intercept the course of the Turkish ship, in face of a hail of projectiles which fell around him, but the torpedo would not explode since its conducting wires had been cut in two places by bullets, and at this moment the bow of the "Choutka" was pierced by a bullet or case shot; the boat however, going at full speed, succeeded in escaping. Skrydloff and four of his companions were wounded.

(VIII.) Day affair near Nicopolis (23d June, 1877).—During the course of this day, a Turkish monitor, commanded by an English officer, left Nicopolis and proceeded down the Danube. Two steam boats armed with spar torpedoes waited for her as she passed, hiding themselves behind a little island. They darted at her at full speed. The monitor let fall rapidly round her side nets hung to booms, each one carrying a torpedo at its extremity, opening at the same time a lively fire of artillery and musketry. One of the Russian boats, the "Mina," had the wires of her torpedoes cut, and suffered such damages as obliged her to haul off. The other, the "Choutka,' commanded by Niloff, vainly struggled to reach the hull of his enemy; stopped by the booms and nets, pierced by a splinter of a shell, driven on shore by the monitor, she had great difficulty in saving herself. Although the crews of the Russian boats were protected by screens and iron shields, they had four or five wounded on that day.

(IX.) Affair at Soukhoum Kalé (night of 23d August).—In reading the account of this engagement, which M. Chardonneau has given, we understood that the weapons employed by the Russian boats were spar torpedoes, one of these boats having been, in fact, half filled by the column of water from the explosion, and another sunk on approaching the Turkish ship, circumstances which would seem to indicate a very close attack; but a recent note by M. Chardonneau in the "Révue Maritime," of November, 1878, the report written by Captain Makaroff, of the "Constantin," as well as certain information from Turkish sources, seem to point out that the engines used by the Russians against the "Assar-i-Chefket" were "diverging" (towing) torpedoes.

Profiting by the night of the 23d August, on which there was an eclipse of the moon, the "Constantin" stopped some six miles from Soukhoum Kalé. Some Turkish ironclads frequently moored before this place, which had recently fallen into the hands of the Sultan's troops. The four torpedo-boats of the "Constantin," headed by Lietenant Zatzarennyi, started off with the inten-

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tion of seizing the moment of the eclipse to enter the roads of Soukhoum. Towards half-past two in the morning, they perceived a Turkish ironclad at her anchorage. This was the corvette "Assar-i-Chefket," commanded by a brave officer who had served some time in the English navy. Hence there was good watch kept on board this ship, several boats were guarding her, and large fires lit on the shore illuminated all the roadstead. The Russian boats were, in consequence, early received by a lively fire from the "Assar-i-Chefket," and from the batteries of Soukhoum. The "Sinope" and the "Navarino" succeeded, nevertheless, if we are to believe the officers commanding these boats, in exploding their torpedoes against the starboard side of the ironclad; the crew of a Turkish boat, hauled up alongside the "Assar-i-Chefket, was actually engaged for a moment in a hand-to-hand fight with the crew of the "Sinope," using their stretchers for arms. The "Navarino" was half filled with water by the columns from its torpedo. The Russian boats "Tchesmé" and "Mina" had steered towards another vessel, but, on making her out to be a merchant brig, they returned towards the "Assar-i-Chefket." The "Mina" exploded her torpedo against the starboard side of the ironclad, the "Tchesmé" attempted the same manœuvre, but as she approached the "Assar-i-Chefket," the rolling of the latter, caused by the explosion of the "Mina's" torpedo, would have infallibly upset the boat. The Russian boats rejoined the "Constantin" with all speed. This attempt, they say, did not even cost them one wounded. Such is the account of the battle of Soukhoum from Russian sources. The "Assar-i-Chefket," however, only suffered slight damages, since after a stay at Constantinople, from 31st August to 12th September, she proceeded to cruise on the coasts of the Adriatic. Her captain besides affirms that on the night of the 23d August, only one of the torpedoes directed against him was fired, and that the explosion was not even effected when in contact.

(X.) Second affair of Batoum (night of the 27th December).—About ten o'clock in the evening the "Constantin" stopped five miles from Batoum and lowered her four torpedo-boats. The night was perfectly dark, a fine rain was falling, and the sea was only ruffled by a slight swell. Lieutenant Zatzarennyi, who had, as before, the command of the Russian boats, had some difficultly in finding his way in the darkness. However, about midnight he rounded the point of Batoum, and observed two large ironclads lying at single anchor, bows outwards, with their sterns moored to the shore. They noticed round them neither obstructions nor guard-boats. Each of the Russian boats, "Tchesmé" and "Sinope," was armed with a Whitehead torpedo. The former carried her tube under the keel, the latter had hers arranged on a raft which she towed. Arrived at about seventy yards from the nearest Turkish ironclad, the two boats fired their torpedoes almost simultaneously; that of the "Tchesmé" exploded on the beam of the enemy's ship, that of the "Sinope" appeared to strike the stern of the ironclad. Their course would easily be followed on the surface of the water. Not till then did the ships and Turkish batteries open their fire on the Russian boats, which rejoined the "Constantin" with all speed. On the way the "Tchesmé" got rid of her injection tube.

The Turkish ship attacked by the Russians boats had not suffered any serious damage. M. Chardonneau thinks that the "Tchesmé's" torpedo struck a rock, and that of the "Sinope" did not explode. But may we not suppose that the Russian torpedoes exploded against under-water defences arranged by the Turks?

(XI.) Third attack at Batoum. Destruction of a Turkish war ship (night of 25th January, 1878).*—On the 25th January, at half-past eleven at night, Captain Makaroff again stopped five miles from Batoum, and sent off, under orders of Lieutenant Zatzarennyi, the two boats "Tchesme" and "Sinope," each armed with Whitehead torpedoes. The weather was cloudy, but towards two in the morning, the moon rising, enabled the Russians to distinguish perfectly the ships moored before Batoum. One of these was an unarmored cruiser

* According to Hobart Pasha, this never occurred; no ship was destroyed at this time and at this place.—Ed.

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of 1,200 or 1,500 tons, anchored at the head of the bay. The "Tchesmé" and the "Sinope" steered for her, and when about eighty yards from her beam, simultaneously fired their Whitehead torpedoes. Both exploded, and in less than three minutes the Turkish vessel entirely disappeared. The Russian boats successfully returned to the "Constantin."

II.

When acts of war are studied with the intention of deriving therefrom useful lessons, it is necessary to bear in mind the relative worth of the *personnel* and of the *material* which are employed in each encounter by the two belligerents. A victory gained by forces wisely organized over barbarians without discipline and unpossessed of deadly weapons, proves, from a military point of view, nothing; a success, which the troops or navy of one powerful nation owe to the employment of improved weapons, over adversaries equally powerful, nearly always furnishes examples well worth our consideration. Now, in the case which we are considering, it is certain that during the two last years of the great American War, that is, at the time of the destruction of the "Houssatonic" and of the "Albemarle," both Federals and Confederates possessed sailors, devoted up to the point of heroism, admirably cognisant of the details of their business, and furnished with weapons, often of most recent invention, which were not for that reason less formidable in their hands. We have only described the strange career of the submarine boat, commanded successively by Payne and Dixon, for the purpose of showing to what a pitch certain Americans then pushed their self-devotion.

In the Turco-Russian War, the adversaries whom we find opposed equally merit the most serious consideration. The sailors of the Czar's fleet gave such decisive proofs of their bravery, audacity, and dexterity in handling their torpedo boats that it would be superfluous here to extol their military virtues. Amongst the Turks, courage and devotion were not less remarkable. Recalling the destruction of the "Seife," until the moment when this monitor sank beneath the waves of the Danube, her intrepid defenders remained at their stations, pouring fire on the enemy! The Osmanli have, it is true, the reputation of keeping a bad look-out, but it should not be forgotten that during the later engagements, the Sultan's Navy was commanded by an English officer of the greatest energy, Hobart Pasha, and that several of his ships were manoeuvred by captains of the same nationality If the watch kept was defective at Matchin and in Batoum Roads, it was perfect, nevertheless, at Sulina and before Soukhoum Kale. Thus, on the Danube, as well as in the Black Sea, the Turkish sailors were worthy foemen for the Russians.

This point once established, let us examine the actions which have been recounted. When, for the first time, the Americans employed the torpedo as the offensive weapon of boats, the latter seemed threatened with three dangers, which must inevitably, it was feared, cause their loss; if the direct effect of the "water-blow" did not stave in their bottoms; if the column thrown up by the explosion did not fill them, extinguishing the fires in their boilers, how were they to escape the hail of bullets, case-shot, and balls hurled by a watchful enemy? After the American War, after the destruction of the under-water boat commanded by Dixon, of the steam pinnace of Cushing, and of the "David," which tried to sink the "Ironsides," one certainly considered as sacrificed, beforehand, every torpedo-carrying boat which was despatched against an enemy's ship. Soon, however, numerous experiences came to show that a well-built torpedo boat had nothing to fear from the shock, or from the thrown-up water. The fights at Matchin, Sulina, and Soukhoum Kale thoroughly confirm these opinions. In fact, several of the boats employed by the Russians, especially at Matchin, were far from presenting the guarantees of strength, which the beautiful boats specially constructed for torpedo work of the present day possess; none, however, of them were lost in consequence of the torpedo which they carried. If the under-water boat of Lieutenant Dixon, and the "David," directed against the "Ironsides," were less fortunate, it is only to be attributed to their defective construction. In respect of

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Lieutenant Cushing's boat, it seems proved that its loss was caused by a shot from the "Albemarle."

The fire of guns, mitrailleuses, and rifles—these are the only real dangers which the torpedo boats have to fear. Before the Russo-Turkish War, many seamen considered this risk as so serious, as to place in doubt the efficacy of a direct attack by boats armed with torpedoes, not only in the daytime against a vessel under weigh, but even at night against a vessel at anchor, if a good look-out were kept. We may believe now that a torpedo boat, suitably built, does not run any exceptional danger. What, in fact, do the engagements just quoted teach us? Leaving aside boats which did not directly contribute to the results, whose crews, though present on the spot, were not actively engaged, neglecting also the American boats, which were victims only to their defective construction, we see that during the Turko-Russian and American Wars, sixteen torpedo boats attacked enemy's vessels, with torpedoes of different descriptions. Now, of these sixteen boats, only two were destroyed, Lieutenant Cushing's pinnace and Lieutenant Poustchine's boat; the latter officer even avows that he sank the boat himself, as an accident to the machinery, suffered after the engagement, would certainly have caused her to fall into the enemy's hands. Finally, several of the Russian attacks were made under most unfavorable circumstances; at Matchin, the "Xenia" was immovable for ten minutes under the fire of the "Seife," before attacking her; at the engagement at Sulina, boats Nos. 1 and 2, after having cleared the rope obstruction of the "Idjalick," occupied a relatively long time in disengaging themselves; before Soukhoum, the four boats which fought the "Assar-i-Chefket" were made out at a considerable distance by the Turks. But these are nothing compared to the temerity which the Russians displayed during the affairs of Rustchuk and Nicopolis in broad daylight. The officers declare that at the latter of these actions the "Choutka" remained exposed for an hour to the fire of her adversary—a Turkish monitor, well armed and perfectly commanded—and, nevertheless, the "Choutka" succeeded in escaping, just as the "Mina" saved herself, and just as the boats employed at Matchin, Sulina, and Soukhoum Kale escaped.

Some recent experiments have shown that a fast steam launch, when pierced by one or more balls of the size of case-shot, is in no danger of sinking if it continue at high speed. This fact was confirmed, on different occasions, during the Russo-Turkish War. The "Choutka" was pierced at Rustchuk by a tolerably-sized projectile, and at Nicopolis by a grape-shot, and on both occasions kept herself afloat by going at full speed; near Matchin, the Russian boat "Djiguite," of only moderate speed, received a bullet which pierced her stern; she had time, nevertheless, to beach herself, and was able to stop her leak in a few minutes.

Will not the crew of a torpedo boat be more endangered than its hull, under the hail of bullets, grape and case, of the enemy? Examination of the different actions of the Turco-Russian War permits us again to answer this question. Taking, first, the night affairs; one wounded, such is the only loss suffered by the eleven torpedo boats, which, exclusive of the boats themselves destroyed by one means or another, attacked different ships. In the engagements, relatively prolonged at Matchin and Sulina, not a Russian was touched by the Turkish projectiles, and, for all that, several of the boats which Doubaroff and Zatzarennyi led were simply protected by screens, or by half-made roofings.

In each of the two day affairs, at Rustchuk and at Nicopolis, the assailants lost three or four wounded, but there again they were most imperfectly sheltered from the enemy's bullets. It may well be asked by what miracle the "Choutka" and her crew escaped, on the 23rd June, from the continued and prolonged firing of the monitor which they had so pluckily attacked. The artillerymen of the Turkish ships possibly were not very well drilled, but the riflemen have not usually been considered more inexpert than others, and we repeat that some of the Ottoman ships, pre-eminently those commanded by English officers, proved in this war that they were capable of rendering good service.

Hence, and present experience shows it, the attack by day or by night

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of a well-built torpedo boat against a vessel at anchor or under weigh does not present exceptional danger, either for the boat herself or for her crew.

In all coast wars, then, the employment of torpedo boats is possible, but will it be really efficacious? The first part of this article has shown us that, out of fourteen attacks made by torpedo boats, four compassed the destruction of the ship, three have caused more or less serious damage to the enemy; the others appear to have been resultless. Now, in each of these affairs, the *materiel* and *personnel* exposed by the assailants to the fire of their enemy were hardly worth mentioning—ten or twenty men and one or more boats, worth together from 15,000 to 100,000 francs. And it was with forces small as these that they succeeded once in three times in destroying a ship manned by hundreds of men, and the cost of replacing which was measured by millions of francs. Is not such a result sufficiently conclusive?

Let us notice also the conditions under which the pre-described attacks were made. The American torpedo boats employed during the war were all, as we have already seen, singularly defective; many also of the Russian boats employed during the last war against the Turks left much to be desired. Have the torpedoes themselves which were employed by the assailants always given sufficient proofs of their efficacy? Not so; for the diverging torpedo of the "Tchesme" would not even ignite in the first affair at Batoum, and was not able to be used at Sulina: again, at Soukhoum the explosion of these torpedoes—probably of a similar description—only caused trifling damages to the "Assar-i-Chefket."

Another question—The Russian crews were excellent, but did they always manoeuvre their torpedo boats in the most judicious manner? During the first affair at Matchin four boats were under the orders of Lieutenant Zatzarennyi, but only one, the "Tchesme," attempted to use her torpedo. This, then, we pronounce, was a very trifling attack. If the boats had together charged the Turkish ironclad which was attacked by the "Tchesme," would the result have been the same? In the Danube, near Matchin, the intention of Doubaroff was to engage successively each of the enemy's ships, only using one boat at a time; from this cause three boats remained stationery for ten minutes under the fire of the Turks. Would it not have been more decisive, and less dangerous, to have attacked simultaneously the "Seife" with the "Czarwitch" and the "Xenia," and the armored gunboat with the two other boats? It is enough to read the account of the fight at Sulina to see that in this case the plan of the Russian officers was badly laid. Alone of all the night attacks made during the last war, those against the "Assar-i-Chefket" and the ship sunk before Batoum, were conducted in a faultless manner.

The affairs of Rustchuk and of Nicopolis deserve special attention. Such an attack, made in broad daylight, against a ship under weigh, has none of the same characteristics as a night attack. In the latter, the object of the assailants is to surprise an immovable vessel; one boat alone is sufficient to obtain the success; the destruction of the "Houssatonic" and the ruin of the "Albemarle" prove this incontestably. In the former case, on the contrary, it is necessary to fight an enemy on his guard, who sees his enemy approaching from afar, and can manoeuvre quickly. Several boats should then unite their endeavors to divide his attention and augment their own chances of success. The attacks of the "Choutka" and "Mina" were therefore almost fatally condemned to failure, for, in an action like that of Rustchuk or Nicopolis, the co-operation of four boats, at the least, seemed necessary.

Thus the torpedo boats of America and of Russia have fought the majority of their actions under circumstances unfavorable to the efficacy of their weapons. This consideration causes the practical worth of an arm to stand forth, the record of the success of which on the field of battle is one overwhelming success to two checks.

We have noticed that in each of the affairs at Rustchuk and at Nicopolis, the Russians suffered the loss of four or five wounded; in nearly all their night attacks, on the contrary, they did not lose a single seaman from the fire of the enemy. This fact quite proves that if ordinary boats may be utilized to surprise a vessel in the midst of darkness, a day

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attack requires special boats—fast, turning rapidly, presenting as small a target as possible to the enemy's gunners, and the crew of which should be absolutely protected against musketry. Grape and case can pierce the boat, but the experience gained at Rustchuk and Nicopolis shows us that if the engines remain unharmed, the boat escapes by keeping up a high speed. Hence great lightness of hull, rapidty of movement and turning, small dimensions, musketry protection limited to the machinery and the fighting posts of the crew—such seem to us to be the principal requirements which boats specially built for torpedo fighting should fulfill.

Proceeding with our subject, we will now endeavor to determine what sort of torpedo, according to different circumstances, is best employed in boats.

During the first affair at Batoum, and before Sulina, the "Tchesme" vainly endeavored to use a "diverging torpedo."* If, as we believe, the "Assar-i-Chefket" was attacked by weapons of the same description, the inefficiency of the three explosions on this occasion will singularly enforce the arguments employed against their use. The captain of the Turkish ironclad, we saw, affirms that one only of the Russian torpedoes exploded. There is nothing surprising in this contradiction between the relative accounts of the affair at Soukhoum. In the midst of darkness, of disturbance produced by the repeated discharges of heavy guns and of musketry, the assailants might very well have taken the explosion of a heavy gun for that of a torpedo blowing up, at over forty yards distance from their boat; or those attacked might not even have heard the noise caused by this latter explosion. We do not know what was the exact method of igniting the torpedoes used against the "Assar-i-Chefket," but if we admit the accuracy of the Russian accounts, how are we to explain the inefficiency of the three explosions? Was the Turkish vessel protected by a ring of floating baulks of timber, kept at a slight distance from the hull, and against which the enemy's torpedoes struck and exploded? No report gives any support to this suggestion. From whatever cause it arose, the failure of the diverging torpedoes of the "Tchesme" was sufficient to cause the rejection of these machines from use in boats. It was seen, in fact, that they might become for the assailants a cause of delay and of mischief, spoil the boat's maneuvering, and place her, in a word, in a most critical position under the fire of the enemy. Still, might not all these inconveniences be compensated for by very great chances of efficacy? Certainly not. The slightest floating protection will stop the diverging torpedo. Ropes stretched between two booms will throw off its towline and save the ship from all danger.

Reasoning, therefore, founded on the experience acquired during the Russian War, leads us to reject entirely the employment of divering torpedoes from boats.

The actions which we have described at the commencement of this article present three complete successes out of six attacks made by means of the spar torpedo. But, as we have seen, the torpedo boats employed by the Americans during the war were defective, and also the affairs of Rustchuk and Nicopolis were undertaken under conditions peculiarly unfavorable to the assailants. The destruction of the "Houssatonic" and of the "Seife" show that the spar torpedo is, during the night, a terribly effective weapon against vessels at anchor, unprotected by external defences. That of the "Albemarle" and the fight off Sulina prove that such a defence is sometimes insufficient. We know, in fact, that during the night of the 10th of June the Russian boats of Lieutenants Rojdestoonski and Poustchine cleared the obstacles which surrounded the "Idjalick." That their torpedoes did not destroy this ship was because they were struck by a projectile, or met some obstacle inside the "stockade" arranged by the Turks. However, this stockade was possibly, in fact probably, the chief cause of the failure of the Russians, since it detained them for some minutes under the fire of the "Idjalick," produced amongst them momentary disorder, which prevented them working their torpedoes with all the coolness desirable. Now, however rapidly the torpedo spar may be worked, there must always be

* Evidently some form of Harvey torpedo, to be ignited by electricity.

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the greatest difficulty in immersing the apparatus, during the short space of time which the boat occupies in passing over the space which separates the vessel from her defences. In the day affair at Nicopolis it was similarly the nets and booms of the Turkish monitor which presented an impassable barrier to Lieutenant Niloff's boat. Relative powerlessness against a vessel defended by exterior obstacles, then, is the principal objection which can be made to the employment of the spar torpedo.

The Russians attribute the premature explosion of the two torpedoes which they were using against the "Idjalick" to their being struck by a projectile; at Rustchuk the torpedo of the "Choutka," at Nicopolis that of the "Mina," could not be fired, according to the Russian officers, because their wires had been cut by bullets. Should we not rather look for the cause of these four failures in the defects of the weapons employed by the Russians, in the over hurry of their maneuvers, or in some blunders made when under the enemy's fire? In fact, experience proves that the impact of bullets or grape-shot cannot explode a torpedo, unless they act directly on its priming; and, also, two conducting wires are a very small target for musketry; besides, there is nothing to prevent these wires being protected by means of the torpedo spar itself. If we must give absolute confidence to the Russian reports, a most improbable chance brought about, on four different occasions, accidents, which the fallibility of men, even the most practical and the bravest, explains much better. Hence we cannot consider the damage to which the enemy's fire subjects the spar torpedo as a serious objection to their use.

We have only been able, unfortunately, to cite two actions in which the assailants used the Whitehead torpedo; one was a check, the other a complete success for the Russians. What actually occured at that second affair of Batoum? M. Chardonneau believes that the "Tchesme's" Whitehead struck a rock; since this torpedo was fired at only 70 yards from the Turkish ironclad, we must then believe that this ship was herself very close to the reef; the slightest change of position would have put her on shore. It is not probable that her captain should have chosen, in the vast Bay of Batoum, such a perilous position. May we suppose that the Russian torpedo met some submarine defences arranged by the Turks? The latter were, doubtless, competent to attempt such a system of defence, but no accounts credit them with such an effort.

It is necessary to search elsewhere for the explanation of the Russian failure. When they attacked, the night was very dark, consequently they may have considerably misjudged the distance which separated them from the enemy. Every seaman knows that in profound darkness the loom of a large ship suddenly appearing presents a misleading idea of height and length. The Russian officers profess to have followed on the water the track of the "Tchesme's" torpedo on its way to the beam of Turkish ship, but the adjusting of a Whitehead torpedo is a most delicate operation; so that, in their path, these machines do not always follow a straight line. It is, therefore, very possible that the Russians fired their torpedoes at a much greater distance than 70 yards from the Turk, and that they, swerving slightly, passed astern of the vessel, and struck the reefs of the neighboring shore. This supposition appears even more admissible, since from the reports of the Russian officers, the "Sinope's" Whitehead took a direction towards the stern of the ironclad.

Besides, the methods adopted for discharging the torpedoes from the "Tchesme" and from the "Sinope" were probably defective; a movable tube under the boat's bottom, or the expedient of an accompanying raft, do not seem to us to be very convenient arrangements for pointing a Whitehead. Did the Russians improve these arrangements before the third affair at Batoum? We do not know; but the rapidity with which the attacked Turkish ship sank would lead us to suppose that both the Whiteheads fired in this case by the "Tchesme" and "Sinope" reached their destination.

We see that on the Danube the Russians made no attempt with the Whitehead. Rivers, and sea coasts with strong tides, and all estuaries with currents, are essentially unfavorable to the employment of these engines, even

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against vessels at anchor. Both the boats and the torpedoes find themselves, then, subject to too many exterior influences for pointing of the torpedo to be performed with accuracy; a rough sea renders also very ticklish, or even impossible, the discharge of a Whitehead, and finally the difference in density between salt water and fresh might possibly be a great obstacle to the employment on rivers of Whiteheads experimented on and regulated in a maritime port.* Thus, deviations arising from an incorrect estimate of distance, defective adjustment of the rudder, inaccurate pointing, and exterior influences affecting its direction or its depth of immersion, such are the gravest inherent difficulties in the use of Whitehead torpedoes from boats.

Based principally on the experience acquired in the Russo-Turkish War, the foregoing discussion permits us to define the circumstances which appear favorable either to the effective use of spar torpedoes or of the Whitehead torpedo; firstly, against ships at anchor, and secondly, when under weigh.

When a vessel is anchored in the middle of a strong stream, it is very difficult to establish a defence round her waterline, or even a good defensive arrangement of nets and spars from her hull. We have just seen that similar circumstances, above all, with a dark night and a rough sea, render also very uncertain the aim of a Whitehead. Spar torpedoes should then be employed in preference, by boats charged to attack: the darkness will also enable these latter to evade more easily than on a bright night the look-out of the patrol boats and of the enemy's sentries.

When, on the other hand, the night is not too dark, when the sea is calm, and the absence of current permits the attacked vessel to defend herself by exterior defences, the employment of Whiteheads presents good chances of success, which are unattainable for the spar torpedoes.

The opportunity of attacking a vessel under weigh by torpedo boats may offer itself as well by day as by night. No engagement argues for or against the employment of Whiteheads under such circumstances; but the affair at Nicopolis shows that a ship of ordinary speed can protect herself effectively against the employment of spar torpedoes by an arrangement of nets and spars. The use of Whiteheads under such circumstances is thus naturally suggested. We must not forget, however, that the speed of the enemy's ship adds a considerable element to the external causes which render the aim from boats very uncertain. Summing up, it would appear wise to introduce into flotillas intended for coast defence some boats armed with spars, and some with Whitehead torpedoes.

In conclusion, we quote a simile, the truth of which has struck us. The spar torpedo is the dagger which a determined man plunges into the body of an enemy who does not protect himself with a coat of mail; the Whitehead torpedo is the bullet which, easy to discharge from afar, kills the enemy in its path, but which very often strays uselessly far from its mark.

Till now, we have only examined the actions fought by the torpedo boats from the point of view of the assailants, let us see if they offer us any useful hints as to the defence. That the "Minnesota," "Wabash," and the "Memphis" were neither sunk nor seriously damaged by the Confederate "Davids" was owing chiefly to the extreme watchfulness of their crews; but the "Houssatonic," which was on her guard, since she had slipped her cable at the moment of the explosion, was, nevertheless, destroyed by Lieutenant Dixon's boat. The Turkish ships moored at Matchin and before Soukhoum Kale had patrol boats out, but yet the "Seife" was sunk, and the "Asar-i-Chefket" only escaped the same fate through the bad management of the weapons brought against her. One sees, therefore, that the most careful watchfulness is not always sufficient guarantee against the attack of torpedo boats. All the actions which we have reviewed show equally, in a most decided manner, the inefficiency in these cases of a defence based solely on artillery and rifle fire. On the other hand, if the "Albemarle" was sunk in spite of the stockade around her, we have seen that simple ropes stretched round the "Idjalick" baulked

* *Note by Translator.*—This objection is slight, as all our Woolwich torpedoes are regulated in fresh water, the difference between their performance in that and in salt water being inappreciable.

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the efforts of the Russians, and that the monitor attacked before Nicopolis probably owed her escape to the nets and spars extended from her hull. The objection is raised to the use of such systems of defence, of the necessity of a ship liable to the attacks of torpedo boats being always ready to get under weigh; but the example of the "Houssatonic" proves that this latter precaution is insufficient to save a ship from the attack of a fast torpedo boat. Besides, need the getting under weigh be prohibited by a system of nets and booms arranged round the vessel? Decidedly not, since the Turkish monitor at Nicopolis used this species of defence while actually under weigh. Such a feat cannot have too much importance attached to it, which has demonstrated practically the possibility of defending, externally, the hull of a steamer under weigh; and, hence, the necessity of seriously studying this subject. We are well aware that in the open sea, even at slow speed, the employment of nets and spars would be impossible, but it is nearly always at mouths of rivers, in narrow passages, and in roadsteads, in generally calm water, that ships will have to defend themselves against the attacks of torpedo boats.

In addition, or in default of spars and nets stretched from the hull, a ship at anchor can, under certain circumstances, protect herself effectively by means of "stockades" attached to boats or to buoys moored around her. It was thus that the Turkish stockade at Sulina was made that baffled the efforts of the Russian torpedo boats. The Ottoman ships at Batoum were in excellent positions for following that example. Their bows fast to an anchor ahead, and their sterns moored to the shore, they had every facility for establishing a good stockade some yards from their hulls, which would have been practically immovable. It is evident that in tideways, or variable winds, a ship swinging to her anchors could not adopt similar arrangements, in consequence of the too great room required for her movements.

Hence, the events of the Turco-Russian War seem to indicate the following measures as the most advantageous for the protection of a ship against the attacks of torpedo boats, to be combined according to the different circumstances which present themselves. One watch of the crew to sleep at their quarters all the night; machine guns and guns of small caliber loaded and depressed in advance; steam up and cables ready to slip; a system of nets and booms extended from the ship; a stockade of the description of that employed by the Turks before Sulina; rowing boats protecting this stockade, armed with guns or machine guns; and, finally, at a distance of not less than 100 yards, one or more boats under steam, their object being to give the alarm, and yet more to rush with all speed on an enemy's boats, which might be preparing to use Whitehead torpedoes. A vessel thus prepared may not be invulnerable, but she would have, we believe, much the best chance on her side.

Conclusion.

In summing up, these are the conclusions to which we bring our examination of the engagements passed in review in the first part of this article.

1st. The attacks made by torpedo boats during the American and Turco-Russian Wars were delivered under conditions such that their results ought to be taken into serious consideration, with the view of extracting information. These results appear to establish the following points:

2nd. An attack made against a ship by means of a torpedo boat does not require more exceptional circumstances, nor more absolute devotion, than any other operation of naval war.

3rd. An attack of this description, where the assailant only risks forces relatively small, offers such chances of success that it should always be tried when the occasion presents itself.

4th. One single torpedo boat, of moderately good quality, is sufficient to surprise at night a vessel at anchor; a day attack, on a vessel under weigh, requires the co-operation of several torpedo boats, especially built for the purpose.

5th. Under all circumstances where such boats, collected into a flotilla, have to attack one or more ships, their attacks should be simultaneous.

6th. The use of "diverging torpedoes" in boats should be discontinued.

7th. Spar torpedoes are usefully em-

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ployed by boats attacking, on a very dark night or with a slightly agitated sea, a ship moored amongst strong currents, or which may be expected not to be protected by external defences.

8th. Whitehead torpedoes will be employed by preference when the night is comparatively clear, the sea very calm, the current slight, and when one may suppose the enemy's ship to be provided with obstacles.

9th. Against a vessel under weigh, the two species of torpedoes will both respectively find their value, according to circumstances. It would appear, then, to be best to combine, in a flotilla intended for the defence of harbors and roadsteads, both spar and Whitehead torpedo boats.

10th. Whenever circumstances will permit, a ship at anchor should guarantee herself against the attack of torpedo boats, not only by the help of a good watch on board and abroad, but also by obstacles attached to her, or by an independent stockade, or even by combining the two systems.

11th. Finally, in certain circumstances, a ship under weigh may defend herself advantageously against torpedo boats by booms and nets.

It is necessary to add that we have not the slightest pretension to laying down here what are termed the principles of torpedo warefare. We have simply endeavored to draw some useful information from the conscientious examination of the different sea fights in which torpedo boats have taken part.

The torpedo is an arm too recent not to undergo, before long, transformations which may considerably modify its method of employment. In the meantime, let us profit by the lessons taught us by these seamen, the first who have used these redoubtable weapons of war

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THE GEOMETRICAL INTERPRETATION OF IMAGINARY QUANTITIES.

Translated from the French of M. Argand by Prof. A. S. HARDY.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

III.

22. Let us now assume some point other than the center K (Fig. 16), as V, and find the product of VA, VB, VC, ..., VG.

Since $\overline{VA}=\overline{VK}+\overline{KA}$, and $\overline{VB}=\overline{VK}+\overline{KB}$, ... we have

$$\overline{VA}.\overline{VB}.\overline{VC} \ . \ . \ . \ \overline{VG}= (\overline{VK}+\overline{KA})(\overline{VK}+\overline{KB}) \ . \ . \ . (\overline{VK}+\overline{KG})=\overline{VK}^n+\Pi'.\overline{VK}^{n-1}+\Pi''.\overline{VK}^{n-2}+ \ . \ . \ . \ . \Pi^{(n-1)}.\overline{VK}+\Pi^{(n)}.$$

Now we have just seen that the coefficients Π', Π'', Π''', . . . , to $\Pi^{(n-1)}$ are zero, and that $\Pi^{(n)}=-(-1)^n$. Hence

$$\overline{VA}.\overline{VB}.\overline{VC} \ . \ . \ . \ \overline{VG}=\overline{VK}^n-(-1)^n =(-\overline{KV})^n-(-1)^n=(\overline{KV}^n-1)(-1)^n.$$

To construct $\overline{KV}^n$, lay off $\overline{AKU}$ equal to n times $\overline{AKV}$. Make $KU = KV^n$, whence $\overline{KU}^n = \overline{KV}^n$. Therefore

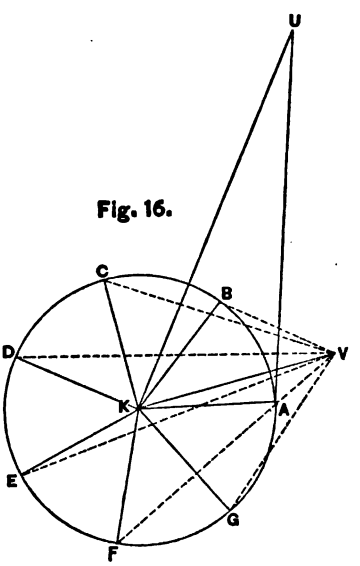

Fig. 16.

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$\overline{KV}^n-1=\overline{KU}-1=\overline{KU}-\overline{KA}$
$=\overline{KU}+\overline{AK}=\overline{AU},$

and $\overline{VA}.\overline{VB}.\overline{VC}\ldots\overline{VG}=(-1)^n\overline{AU}.$

If we consider VA, VB, ... , VG and AU as positive prime lines, we may make $\overline{VA}=r'.VA, \overline{VB}=r''.VB, \ldots, \overline{VG}=r^{(n)}VG$ and $\overline{AU}=\rho.AU$; $\rho, r', r'', \ldots, r^{(n)}$ being directed radii or the roots of unity. We should then have

$r'.r''.r'''\ldots r^{(n)}.VA.VB.VC\ldots VG$
$=(-1)^n\rho.AU,$

and (No. 12, § 8), VA.VB . . . . VG=AU. For example, let KV=x, KU=x^n, the angle AKV=a, the angle AKU=na, the angle AKB=$\frac{2\pi}{n}$. We should then find

$$AU^2=x^{2n}-2x^n\cos na+1,$$
$$VB^2=x^2-2x\cos\left(a-\frac{2\pi}{n}\right)+1,$$
$$VC^2=x^2-2x\cos\left(a-\frac{4\pi}{n}\right)+1,$$
$$VD^2=x^2-2x\cos\left(a-\frac{6\pi}{n}\right)+1,$$
$$\ldots\ldots\ldots\ldots,$$
$$VA^2=x^2-2x\cos\left(a-\frac{2\pi n}{n}\right)+1$$
$$=x^2-2x\cos a+1,$$

and, squaring the equation VA.VB . . . VG=AU, we shall have

$$x^{2n}-2x^n\cos na+1=$$
$$\left\{x^2-2x\cos\left(a-\frac{2\pi}{n}\right)+1\right\}$$
$$\times\left\{x^2-2x\cos\left(a-\frac{4\pi}{n}\right)+1\right\}$$
$$\times\left\{x^2-2x\cos\left(a-\frac{6\pi}{n}\right)+1\right\}$$
$$\times\ldots\ldots\times(x^2-2x\cos a+1),$$

there being n factors in the second member.

The development of the rational factors of the first or second degree of the binomials x^n+1, x^n-1, is obtained by making $\cos na=1$ and $\cos na=0$ in this formula. On this well known fact it is unnecessary to be more specific.

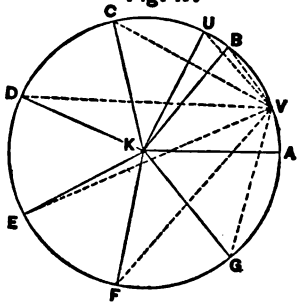
23. If V (Fig. 17) be on the circumference, we have

$$AU=2\sin\frac{na}{2},$$
$$VA=2\sin\frac{a}{2},$$
$$VB=2\sin\left(\frac{\pi}{n}-\frac{a}{2}\right),$$
$$VC=2\sin\left(\frac{2\pi}{n}-\frac{a}{2}\right),$$
$$\ldots\ldots\ldots,$$
$$VG=2\sin\left\{\frac{(n-1)\pi}{n}-\frac{a}{2}\right\}.$$

Hence, substituting a for $\frac{a}{2}$ and

$$\sin\left(\frac{n\pi}{n}-a\right)=\sin(\pi-a)$$

Fig. 17.



for sin a, there results

$$2\sin na=$$
$$2^n.\sin\left(\frac{\pi}{n}-a\right)\sin\left(\frac{2\pi}{n}-a\right)\sin\left(\frac{3\pi}{n}-a\right)$$
$$\ldots\times\sin\left\{\frac{(n-1)\pi}{n}-a\right\}\sin\left(\frac{n\pi}{n}-a\right).$$

Making $a=\frac{\pi}{2n}-b$, we obtain $na=\frac{\pi}{2}-nb$ and $\sin na=\cos nb$. The substitution of these values gives

$$2\cos nb=2^n\cos$$
$$\left\{\frac{(n-1)\pi}{2n}-b\right\}\cos\left\{\frac{(n-3)\pi}{2n}-b\right\}$$
$$\times\cos\left\{\frac{(n-5)\pi}{2n}-b\right\}\ldots\times\cos$$
$$\left\{\frac{[n-(2n-3)]\pi}{2n}-b\right\}\times\cos$$
$$\left\{\frac{[n-(2n-1)]\pi}{2n}-b\right\}.$$

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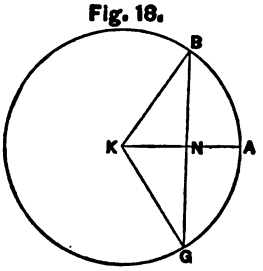
24. In Fig. 18, make the arc AB=arc AG; then $\overline{KN}=\overline{KB}+\overline{BN}$ and $\overline{KN}=\overline{KG}+\overline{GN}$; whence we obtain, observing that $\overline{BN}+\overline{GN}=0$, and that $\overline{KG}=\overline{KB}^{-1}$,

Fig. 18.



$$2\overline{KN}=\overline{KB}+\overline{KB}^{-1}.$$

Raising both members of this equation to the nth power, n being a whole number, it becomes

$$(2\overline{KN})^n=\overline{KB}^n+n\overline{KB}^{n-2}+\frac{n(n-1)}{2}.\overline{KB}^{n-4}+\ldots+\frac{n(n-1)}{2}.\overline{KB}^{-n+4}+n\overline{KB}^{-n+2}+\overline{KB}^{-n}.$$

Making the arc $AB=a$, then $\overline{KN}=\cos a$, $\overline{KB}=\cos a\sim\sin a$, and, in general, $\overline{KB}^m=\cos ma\sim\sin ma$. Substituting these values in the above equation, and, since the first member contains no medial terms, suppressing those of the second member, we have

$$(2\cos a)^n=\cos na+n\cos(n-2)a+\frac{n(n-1)}{2}\cos(n-4)a+\ldots+\frac{n(n-1)}{2}\cos(-n+4)a+n\cos(-n+2)a+\cos(-na).$$

Since, in general, $\cos m=\cos(-m)$, the terms of the second member may be added two and two; but two cases must be distinguished, according as n is even or odd. In the first case, the number of the terms in the second member is odd and the middle term stands alone; this term is

$$\frac{n(n-1)(n-2)\ldots\left\{n-\left(\frac{n}{2}-1\right)\right\}}{1.\,2.\,3\ldots\frac{n}{2}}\cos(n-n)a=\frac{n(n-1)\ldots\left(\frac{n}{2}+1\right)}{1.\,2.\,3\ldots\frac{n}{2}}.$$

In the second case, all the terms are doubled, and, if we begin the series with $\cos na+\cos(-na)=2\cos na$, the last term will be

$$2\frac{n(n-1)(n-2)\ldots\left\{n-\left(\frac{n-1}{2}-1\right)\right\}}{1.\,2.\,3\ldots\frac{n-1}{2}}\cos[n-(n-1)]a=.\ 2\frac{n(n-1)(n-2)\ldots\frac{n+3}{2}}{1.\,2.\,3\ldots\frac{n-1}{2}}\cos a.$$

In the same way may be found the value of $(2\sin a)^n$. We have $\overline{NB}=\overline{NK}+\overline{KB}$, $\overline{NG}=\overline{NK}+\overline{KG}$; but $\overline{NG}=-\overline{NB}$ and $\overline{KG}=\overline{KB}^{-1}$; whence $2\overline{NB}=\overline{KB}-\overline{KB}^{-1}$, and

$$(2\overline{NB})^n=\overline{KB}^n-n.\overline{KB}^{n-2}+\frac{n(n-1)}{2}.\ KB^{n-4}-\ldots\pm\frac{n(n-1)}{2}.\overline{KB}^{-n+4}\mp n.KB^{-n+2}\pm\overline{KB}^{-n}=(\sim 2\sin a)^n.$$

The upper and lower signs correspond respectively to the cases in which n is even or odd. Examine first the former. $(\sim 2\sin a)^n$ is then of the prime order, and the medial terms in the development of the second member may be neglected; whence

$$\pm(2\sin a)^n=\cos na-n\cos(n-2)a+\frac{n(n-1)}{2}\cos(n-4)a-\ldots+\frac{n(n-1)}{2}n\cos(-n+4)a-n\cos(-n+2)a+\cos(-na).$$

In the first member we take the plus sign when n is of the form $4m$, and the minus sign when n is of the form $4m+2$. The middle term, which is

$$\frac{n(n-1\ldots\left(\frac{n}{2}+1\right)}{1.\,2.\,3.\ \ .\frac{n}{2}},$$

as in the formula for the cosine, is not doubled.

In the second case, $(\sim 2\sin a)^n$ is of a medial order. Hence the prime terms of the second member must be dropped, which gives, after dividing the equations by ~ 1,

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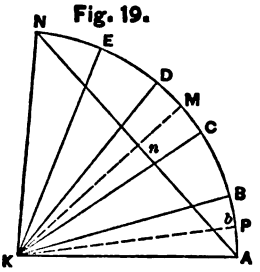
$$\pm(2\sin a)^n=\sin na-n\sin(n-2)a+\frac{n(n-1)}{2}\sin(n-4)a-\ldots-\frac{n(n-1)}{2}\sin(-n+4)a+n\sin(-n+2)a-\sin(-na).$$

The + and − signs correspond respectively to the cases in which n is of the form $4m+1$ and $4m+3$. Here all the terms are equal two and two; for, in general, $\sin m=-\sin(-m)$, and the number of terms is even. Uniting, therefore, as above, the equal terms, the series reduces to $\frac{n+1}{2}$ terms, the last of which is

$$\frac{n(n-1)\,(n-2)\ldots\frac{n+3}{2}}{1.\,2.\,3\ldots\frac{n-1}{2}}\sin a.$$

25. Suppose the arc AN divided into n equal parts AB, BC, ... , EN (Fig. 19).

Fig. 19.



Draw AN and AB and through their middle points, n and b, the radii KM, KP. Then

$$\overline{KB}+\overline{KC}+\overline{KD}+\ldots+\overline{KN}=\cos a\sim\sin a+\cos 2a\sim\sin 2a+\cos 3a\sim\sin 3a+\ldots+\cos na\sim\sin na=C\sim S,$$

where

$$C=\cos a+\cos 2a+\cos 3a+\ldots+\cos na,$$
$$S=\sin a+\sin 2a+\sin 3a+\ldots+\sin na.$$

Let $\overline{KB}=u$, $\overline{KC}=u^2$, ... , $\overline{KN}=u^n$; whence

$$\overline{KB}+\overline{KC}+\ldots+\overline{KN}=u+u^2+u^3+\ldots+u^n=\frac{u^n-1}{u-1}\cdot u=\frac{\overline{KN}-\overline{KA}}{\overline{KB}-\overline{KA}}\cdot u=\frac{\overline{KN}+\overline{AK}}{\overline{KB}+\overline{AK}}\cdot u=\frac{\overline{AN}}{\overline{AB}}\cdot u=\frac{n\overline{N}}{b\overline{B}}\cdot u.$$

But (No. 12, § 4)

$$n\overline{N}=\sim\sin\frac{na}{2}\times\overline{KM}=\sim\sin\frac{na}{2}\cdot u^{\frac{n}{2}},$$

$$b\overline{B}=\sim\sin\frac{a}{2}\times\overline{KP}=\sim\sin\frac{a}{2}\cdot u^{\frac{1}{2}}.$$

Hence

$$C\sim S=\frac{\sim\sin\frac{na}{2}\cdot u^{\frac{n}{2}}}{\sim\sin\frac{a}{2}\cdot u^{\frac{1}{2}}}\cdot u=\frac{\sin\frac{na}{2}}{\sin\frac{a}{2}}\cdot u^{\frac{n+1}{2}}=\frac{\sin\frac{na}{2}}{\sin\frac{a}{2}}\left(\cos\frac{n+1}{2}a\sim\sin\frac{n+1}{2}a\right).$$

Equating the terms of like order, we have

$$C=\frac{\sin\frac{na}{2}\cdot\cos\frac{n+1}{2}a}{\sin\frac{a}{2}}$$

and

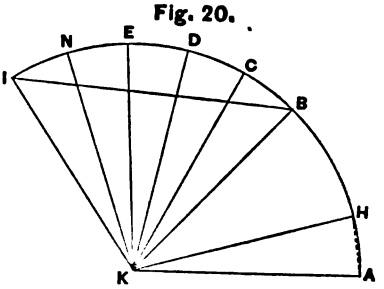
$$S=\frac{\sin\frac{na}{2}\cdot\sin\frac{n+1}{2}a}{\sin\frac{a}{2}}.$$

26. A similar process will lead to the reduction of

$$K=\cos a+\cos(a+b)+\cos(a+2b)+\ldots+\cos(a+nb),$$
$$\Sigma=\sin a+\sin(a+b)+\sin(a+2b)+\ldots+\sin(a+nb).$$

To this end, describe the arcs AB=a, BC, CD, . . . , EN=b (Fig. 20), the latter

Fig. 20.



being n in number. Make, moreover, AH=NI=b, and draw BI and AH. Then if $\overline{KH}=u$, $\overline{KB}=v$, we have

$$\overline{KC}=vu,\ \overline{KD}=vu^2,\ \ldots,\ \overline{KN}=vu^n,\ \overline{KI}=vu^{n+1}.$$

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Therefore

$$K\sim\Sigma=v+vu+vu^2+\ldots+vu^n=\frac{vu^{n+1}-v}{u-1}=\frac{\overline{KI}-\overline{KB}}{\overline{KH}-\overline{KA}}=\frac{\overline{KI}+\overline{BK}}{\overline{KH}+\overline{AK}}$$

$$=\frac{\overline{BI}}{\overline{AH}}=\frac{\frac{1}{2}\overline{BI}}{\frac{1}{2}\overline{AH}}=[\text{No. 12, § 6}]$$

$$\frac{\sim\sin\left(\frac{n+1}{2}b\right).\overline{K.(AB+\frac{1}{2}BI)}}{\sim\sin\frac{1}{2}b.\overline{K.\frac{1}{2}AH}}=$$

$$\frac{\sim\sin\left(\frac{n+1}{2}b\right).\overline{K.(AB+\frac{1}{2}BN)}}{\sim\sin\frac{1}{2}b}=$$

$$\frac{\sin\left(\frac{n+1}{2}b\right)}{\sin\frac{1}{2}b}\left\{\cos\left(a+\frac{bn}{2}\right)\sim\sin\left(a+\frac{bn}{2}\right)\right\},$$

or, equating terms of like order,

$$K=\frac{\sin\left(\frac{n+1}{2}b\right)\cos\left(a+\frac{bn}{2}\right)}{\sin\frac{1}{2}b}$$

and

$$\Sigma=\frac{\sin\left(\frac{n+1}{2}b\right)\sin\left(a+\frac{bn}{2}\right)}{\sin\frac{1}{2}b}.$$

27. What precedes is sufficient to show that the method here presented may be employed in trigonometrical researches. It may also be of some use in elementary geometry and algebra, as will now be briefly indicated.

28. Let Fig. 21 be constructed; its

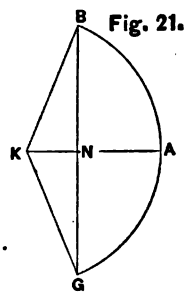

Fig. 21.

simplicity and analogy, with those already made use of, renders its explanation unnecessary. It follows from the rules of multiplication and addition that $\overline{KB}\times\overline{KG}=\overline{KA}^2$, and $\overline{KB}=\overline{KN}+\overline{NB}$, $\overline{KG}=\overline{KN}+\overline{NG}$. Hence $\overline{KA}^2=(\overline{KN}+\overline{NB})(\overline{KN}+\overline{NG})$. Let $KA=h$, $KN=a$, $NB=NG=b$. Then

$$h^2=(a\sim b)(a\sim b)=a^2+b^2.$$

29. Any directed chord $\overline{PQ}$ (Fig. 22) is of the same order and sign as the radius $\overline{KR}$, drawn in the direction of this

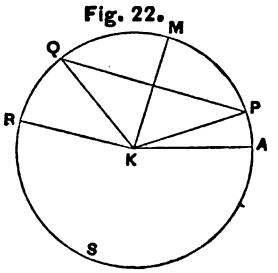

Fig. 22.

chord. Now the angle AKR is equal to $\frac{AP+AQ+\pi}{2}$; for, drawing KM perpendicular to PQ, we have

$$\text{arc AR}=AP+PM+MR=AP+\tfrac{1}{2}PQ+\frac{\pi}{2}=AP+\tfrac{1}{2}(AQ-AP)+\frac{\pi}{2}=\frac{AP+AQ+\pi}{2}.$$

The radius $\overline{KR}$ may therefore be expressed (No. 12, § 6) by $\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)}$, an expression indicating the direction of the chord $\overline{PQ}$. On this expression we also remark that the chord $\overline{PQ}$ being indeterminate, the letters P and Q may be interchanged, and for $\overline{QP}$ we should have

$$\overline{K.\left(\frac{AQ+AP+\pi}{2}\right)},$$

an expression identical with the former; for $AP+AQ=AQ+AP$. We should infer from this that $\overline{PQ}$ and $\overline{QP}$ have the same direction, which is, however, not the case, since they are reciprocally positive and negative. To solve this difficulty we observe that the designation of an arc by its two terminal points, as AP, applies to an infinite number of arcs, as $AP+2n\pi$, n being any integer. In such expressions, then, as the above, of all these arcs that one should be taken which conforms to the construction followed in the establishment of the general formula. Suppose the point Q to move in the direction QRS until it reaches P, and that, at the same time, P moving in the same direction, reaches Q. The chord $\overline{PQ}$ will then be what was

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before the chord $\overline{QP}$. The direction of this chord $\overline{PQ}$ will still be

$$\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)};$$

but, in this last expression, the arc AP should be estimated from A, round the entire circumference, plus the arc AP itself, so that this expression really differs from the former by the quantity $\frac{2\pi}{2}=\pi$, as it should.

To avoid all ambiguity, it is sufficient in the general formula

chord $\overline{PQ}$ *having the direction*

$$\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)},$$

to consider the arc AQ greater than the arc AP, following along the circumference in either direction from A to P to determine the arc AP, and then continuing in the same direction till Q is reached. Thus for $\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)}$ we might write $\overline{K.\left(\frac{2AP+PQ+\pi}{2}\right)}$, the arcs AP and PQ being estimated in the same direction. In addition to the foregoing it may be remarked that, if the chord $\overline{PQ}$ is divided at N into any two segments, the part $\overline{NQ}$ has the same direction as $\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)}$, and the part $\overline{NP}$, which relative to $\overline{NQ}$ is negative, has the direction

$$\overline{K.\left(\frac{AP+AQ+\pi}{2}-\pi\right)}=\overline{K.\left(\frac{AP+AQ-\pi}{2}\right)}.$$

Hence, remembering that in general the product of two lines having the directions $\overline{K.FG}$, $\overline{K.HI}$ is in the direction of $\overline{K.(FG+HI)}$, we conclude that the product $\overline{NP}.\overline{NQ}$ will have the direction $\overline{K.(AP+AQ)}$.

30. Take now any four points P,Q,R,S; remembering that in general $\overline{MN}=-\overline{NM}$, we may write

$$\overline{PS}.\overline{QR}+\overline{RS}.\overline{PQ}=\overline{PS}.\overline{QR}+(\overline{RQ}+\overline{QS})(\overline{PS}+\overline{SQ})=\overline{PS}.\overline{QR}+\overline{RQ}.\overline{PS}+\overline{RQ}.\overline{SQ}+\overline{QS}.\overline{PS}+\overline{QS}.\overline{SQ}=\overline{RQ}.\overline{SQ}+\overline{QS}.\overline{PS}+\overline{QS}.\overline{SQ}=\overline{QS}(\overline{QR}+\overline{PS}+\overline{SQ})=\overline{QS}.\overline{PR}.$$

Now, if the points P, Q, R, S are so situated that the three products of the final equation $\overline{PS}.\overline{QR}+\overline{RS}.\overline{PQ}=\overline{QS}.\overline{PR}$ have the same direction, this equation will be true of absolute lines. This condition will be satisfied if the points in question are taken in the order P, Q, R, S, on the circumference, in which case PQ, QR, RS, PS are the sides of a quadrilateral whose diagonals are PR, QS. In fact, these sides and diagonals being so many chords of the circle, we may, by the formula of the preceding article, form the following table, the origin of the arcs A being supposed to immediately precede the point P:

Chords.	Directions.
$\overline{PS}$	$\overline{K.\left(\frac{AP+AS+\pi}{2}\right)}$
$\overline{QR}$	$\overline{K.\left(\frac{AQ+AR+\pi}{2}\right)}$
$\overline{RS}$	$\overline{K.\left(\frac{AR+AS+\pi}{2}\right)}$
$\overline{PQ}$	$\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)}$
$\overline{QS}$	$\overline{K.\left(\frac{AQ+AS+\pi}{2}\right)}$
$\overline{PR}$	$\overline{K.\left(\frac{AP+AR+\pi}{2}\right)}$

and these expressions will be free from ambiguity, because, on account of the supposed order in which A,P,Q,R and S are taken, these six chords are all taken in the same direction.

Hence, in virtue of the principle cited above, the three products $\overline{PS}.\overline{QR}$, $\overline{RS}.\overline{PQ}$, $\overline{QS}.\overline{PR}$ have the same direction, namely, that of

$$\overline{K.\left(\frac{AP+AQ+AR+AS+2\pi}{2}\right)}.$$

Thus, then, for absolute lines, we have $PS.QR=RS.PQ+QS.PR$. This demonstration, far more simple than the ordinary one founded only on the comparison of similar triangles, is here given only as illustrative of the use of intermedials, of which little has been said.

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31. In this last article we propose to show that every polynomial of the form $X^n+aX^{n-1}+bX^{n-2}+\ldots+fX+g$ is decomposable into factors $X+\alpha$ of the first degree. It is to be noticed that $a, b, \ldots g$ are not necessarily reals, as is ordinarily the case.

It is well known that the problem consists in the proof that a quantity can always be found which, substituted for X, will render the polynomial zero, which latter we make = Y. Denote by $Y_{(p)}$, $Y_{(p+\rho i)}$ the values of Y obtained by making $X=p$, $X=p+\rho i$, p and i being arbitrary numbers and ρ a directed radius or an indeterminate root of unity. We then have $Y_{(p)}=p^n+ap^{n-1}+bp^{n-2}+\ldots+g$, $Y_{(p+\rho i)}=(p+\rho i)^n+a(p+\rho i)^{n-1}+b(p+\rho i)^{n-2}+\ldots+g=Y_{(p)}+i\rho Q+i^2\rho^2R+i^3\rho^3S+\ldots$, Q, R, S being known quantities, dependent on p, n, a, b, c, $\ldots$, and obtained from the development of the powers of $p+\rho i$. If i be supposed infinitely small, the terms containing i^2, i^3, $\ldots$, disappear, and we have simply $Y_{(p+\rho i)}=Y_{(p)}+i\rho Q$. Let $\overline{KP}$ have the direction of $Y_{(p)}$. Assume ρ so that $i\rho Q$ shall have the direction $\overline{PK}$, that is of the same order as $Y_{(p)}$, but opposite in direction; it follows that the magnitude of $Y_{(p+\rho i)}$ will be less than that of $Y_{(p)}$; similarly we may obtain a new value of Y which shall be less than that of $Y_{(p+\rho i)}$, and so on, and finally therefore a value of X for which $Y=o$.

To render the demonstration complete, it must be remarked that the term $i\rho Q$ may become zero. In this case we should retain the succeeding term $i^2\rho^2R$, or, should this disappear, $i^3\rho^3S$, and so on. The reasoning remains the same, because the powers ρ^2, ρ^3, $\ldots$: are quantities of the same nature as ρ.

32. The method above explained rests upon two principles of construction, one for the multiplication, the other for the addition of directed lines; and it has been already observed that inasmuch as these principles depend upon inductions which are not securely established, they cannot, as yet, be considered as other than hypotheses, whose acceptance or rejection should depend upon either the consequences which they entail or a more rigorous logic.

We might have dwelt more fully upon the fundamental ideas which lead to these results. We might have indicated, by some comparisons, how certain points, in the theories of Algebra and Geometry, bear upon these principles admitted by induction, whose truth is established rather by the exactness of their consequences than by the logic on which they are founded; but this discussion would have contributed nothing essential to the foregoing, and we confine ourselves to proposing the method of directed lines as an instrument of research, whose use is advantageous in certain cases, because geometric constructions offer, as it were, a picture to the eye which facilitates purely intellectual operations. Moreover, it is always possible to translate the demonstrations founded on this method into ordinary language.

THE ANNUAL RAINFALL IN ITS RELATION TO THE WATER SUPPLY OF A CITY.

By P. H. BAERMANN, C. E.

Abstract of a Paper read before the Pi Eta Society, Troy, N. Y.

If a vessel is filled with water and exposed to the air, the quantity becomes diminished and after a time entirely disappears. Non-absorbent objects, wet by showers, become dry soon after the sun begins to shine upon them, the water in both cases being evaporated, converted by heat into vapor and diffused through the air.

So evaporation goes on from the entire land and water surface of the earth.

The air is only capable of receiving a certain amount of vapor; this capacity depends principally upon the temperature, increasing with heat and decreasing with cold.

When the limit of absorption is reached the air is said to be at its point of

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saturation, and any further supply floats in the form of clouds or mist, or is returned to its liquid condition and falls to the earth.

As the quantity of vapor in the atmosphere increases, or a fall in the temperature causes its more rapid condensation, the clouds receiving this condensation become heavier and sink to a lower level, the small globules of water of which they are composed become larger, form drops of rain which, increasing in size, fall to the earth. Thus, the supply of all fresh water sources, be it wells, springs, brooks, rivers or lakes, is furnished by the condensation of the vapor in the air, precipitated in the form of rain, dew or snow. As the fresh water upon the earth is so small in area compared with the ocean, we regard the sea as the source of all water supplies.

It will be interesting to consider briefly the causes producing the annual precipitation, the distribution of which varies so greatly in different places and at different seasons, yet locally so regular in its coming and amount that it must be the result of laws as sure in their operation as the seasons in their rounds.

"The sea supplies the winds with food for the rain which these busy messengers convey from the ocean to 'the springs in the valleys which run among the hills.' To the philosopher, the places which supply the vapors are as suggestive and as interesting for the instruction they afford, as the places are upon which the vapors are showered down. Therefore, as he who studies the physical geography of the land is expected to make himself acquainted with the regions of precipitation, so he * * * should search for the regions of evaporation, and for the springs in the ocean which supply the reservoirs among the mountains with water to feed the rivers; and in order to conduct this search properly, he must consult the winds and make himself acquainted with their circuits."

For about thirty degrees upon each side of the equator, and separated by a region of equatorial calms, we have two zones of constant winds extending entirely around the earth; those upon the north called the N. E. trade winds, those upon the south S. E. trade winds, blowing continually and almost invariably in the same direction.

The belt of calms, having a width of about 6 degrees, travels during the year with the sun, back and forth over about 17 degrees of latitude, coming north in the summer and returning, reaches its extreme southern latitude in March or April, thus having a width of from 5 to 7 degrees and a motion north and south of 17 degrees. It is evident that some localities are covered twice annually by this zone, and as within this zone it rains almost constantly there are places which have two rainy seasons.

This zone of calms is formed by the meeting of the two trade winds.

"* Warmed by the heat of the sun, and pressed on each side by the whole force of the N. E. and S. E. trades, these two winds cease to move onward, and ascend.

"This operation is the reverse of what takes place near the 30th parallel. Having ascended to the upper regions of the atmosphere again, the wind travels counter to the N. E. and S. E. trades until it meets, near the 30th degree, the winds from the north and south poles coming to take its place." Another belt of calms occurs here "from under which two surface currents of wind are ejected, those towards the equator being the trades, and those towards the poles the N. and S. W. passage winds." * *

"Hence, we say, that the *primum mobile* of the air is derived from change of specific gravity induced by the freezing temperature of the Polar regions, as well as from change of specific gravity due to the expanding force of the sun's rays within the tropics."

When the trade winds meet and produce the Equatorial calm, the air is heavily charged with moisture absorbed in its passage over large areas of the ocean, and as it cannot escape, except upward, a portion of the vapor is condensed and in this region of calms we have almost constant precipitation.

The balance of the vapor is carried in the upper current until it reaches the 30th parallel, where it becomes a surface wind towards the poles. The decrease in temperature causes condensation, precipitation commences, and, at last reaching the extreme north and south, the whole of the moisture has been extract-

* Maury, "Physical Geography of the Sea."

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ed by the low temperature, and as dry air it commences its return to the equator.

In the passage of these winds towards the tropics, they absorb this water after passing the 30th parallel, being until that time upper currents. Those coming from below the equator pass over an evaporating surface of 75,000,000 square miles, while those from above the equator over only 25,000,000.* We should expect, therefore, that the amount of water carried to the northern hemisphere would be one-third greater than that carried to the southern. The deductions from these physical laws are:

1. That the rainfall decreases from the equator towards the poles.

2. That the rainfall is greater in the northern than in the southern hemisphere.

3. That in the temperate zone more rain falls upon the western coast than upon the eastern, while in the tropics the reverse obtains.

4. That the sides of mountains exposed to the prevailing winds are the wet sides.

5. That the regions of greatest precipitation will be on the slopes of mountains first receiving the trade winds, after having crossed the largest water area.

Let us now compare the above deductions with facts and thereby prove or disprove these laws.

TABLE OF MEAN AND MAXIMUM RAINFALL.

Location.	Lat. and Long.		Years of Record.	Mean Annual Rainfall.	Maximum Annual Rainfall.	Authority.
	N. & S.	E. & W.				
Cayenne.....	4°58′N.	52°12′W	6	188		Be'rdmore
Sierra Leone.	9°±N.	3°± W			313	Pet'rmann
Maranham...	3°±N.	44°± W			280	Johnston
Mahabalesh'n 130 Miles inland from Bombay....	18°53′N	72°31′W	14	254	304	Be'rdmore

The quantity of rain falling in a single day in tropical regions is often immense —thus in Sierra Leone, 26 inches fell in two days—and at Cayenne, Admiral Roussin collected 10 inches in ten hours,

*Maury.

while the average annual rainfall of the tropics is placed by Johnston, at 113 inches in the western, and 80 inches in the eastern hemispheres.

The precipitation in the temperate zone is given at 40 inches in the western, and 34 in the eastern hemispheres. The first deduction is therefore proven.

The rainfall is greater in the northern than in the southern hemisphere, the rain gauge showing a difference of 4 inches. While the greater number and size of the rivers in the former than in the latter discharge the increased quantity. Above the 31st degree of latitude we find the N. W. and S. W. winds prevailing, hence the west coasts of the temperate zone first receive and condense the moisture, while from the 29th degree towards the equator we have the trade winds blowing N. E. and S. E., which give to the eastern shores of the torrid zone the greater rainfall.

Thus—the rainfall on the west coast of England is 45 inches; on the east 27.4.

The eastern sides of the Andes receive the trade winds, and in their passage over them the entire moisture is extracted, owing to the low temperature; then these winds pass over the western slope to the Pacific, incapable of furnishing rain. Thus the coast of Peru is rainless.

*From the 30th degree north in the Pacific, where the N. E. trades first strike the ocean, to the region of equatorial calms, they travel over the sea absorbing the vapors due to a tropical sun. Here, laden as they are, they rise and taking a southeast course, pass as upper current until between the 30th and 40th degree, when they become the prevailing winds of the southern hemisphere, and are first intercepted by the Andes of Patagonia, whose temperature of below 32 degrees deprives them of their moisture. 151 inches of rain in 41 days have been recorded, and Mr. Darwin reports that the sea water along this part of the coast is sometimes quite fresh from the vast quantity of rain that falls.

Thus the great truths of Nature become manifest, and by their study and the arrangement of facts do we deduce the laws which control their actions.

*Maury.

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Thus we learn "that the rain we see descending, was thawed for us out of the icebergs which have watched the polar star for ages, and the lotus lilies have soaked up from the hill, and exhaled as vapor, snows that rested on the summits of the Alps."

Since "the waters under the Heavens were gathered together and the dry land appeared," the annual round of winter and summer, of rain and sunshine, of seed time and harvest have been constant, owing to the laws which govern the atmosphere and the laws which govern the ocean. In what follows, only the United States, occupying the central portion of the northern division of the American Continent, whose shores washed by the Atlantic ocean on the east, the Pacific on the west, the Gulf of Mexico an the south, and the chain of lakes in the north, its breadth from east to west opproximately 2700 miles, and its length from north to south 1600 miles, with an approximate area of 3,000,000 square miles, will be regarded.

This area may be divided, with reference to the precipitation, into three great regions, namely: That of periodical, frequent and of scanty rainfall.

The first comprises the western portion of the Pacific slope; and here we find a marked example of the effect of the winds. As before stated, the belt of equatorial calms has a motion north and south during the year, of about 17 degrees of latitude, and consequently the trade and passage winds which blow in opposite directions cover alternately the same locality, as they are crowded out of their normal positions. This change of wind does not take place above the 40th parallel, and consequently that portion of the Pacific slope above, receives constantly the rain winds; while below the same parallel the coast receives them in spring and winter, and in summer and fall the trade winds.

Place.	Lat.	Amount of Rain.					
		Spring.	Sum'er.	Autumn.	Winter.	Year.	
San Diego.....	32°42′	2.74	0.75	1.24	5.90	10.63	
San Francisco.....	37°48′	8.81	0.03	3.37	11.38	23.59	18.48 Mean
Sacramento.....	38°33′	9.02	0.00	3.74	8.56	21.32	
Fort Oxford.....	42°44′	19.12	3.00	19.60	26.80	68.52	
Fort Vancouver.....	45°40′	9.28	6.23	10.30	19.69	45.50	55.29 Mean
Fort Steilacoom.....	47°10′	11.19	3.85	15.20	21.51	51.75	

The region of frequent rains extends from the Atlantic westward to the 100th meridian. On that portion—along the Atlantic slope as far as Washington, nearly the same annual quantity falls, and is distributed with remarkable uniformity during the year. South of Washington and in the Gulf States, the greater portion of the rainfall occurs in summer.

Place.	Rain in inches.				
	Spring.	Summer	Autumn	Winter.	Year.
Eastport, Me. ..	8.88	10.05	9.85	10.61	39.39
Charleston, S. C.	9.89	17.45	10.06	7.52	44.92
Baton Rouge....	15.08	19.14	12.48	15.40	62.10

The region of scanty rains, from what precedes, would naturally be sought west of the 100th meridian and east of the Cascade and Sierra Nevada Mountains, including the inland basin of Utah, the eastern slopes of the Rocky Mountains, and the lower portions of the Pacific slope.

Among the mountains frequent showers occur, and in exceptional cases the valleys between are well watered; Santa Fe, with an elevation of 6800 feet, and Fort Massachusetts with an elevation of 8300 feet above tide, both situated in the valley of the Rio Grande, have a mean annual rainfall of between 19 and 20 inches.

The annual rainfall of the desert region through which the great Colorado flows, is estimated at 3 inches; that of the Nilan basin of Utah at 5 inches, the larger portion of which is received in winter.

The greatest amount of rain reported*

* Army Meteorological Register.

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for any given year, was in 1846, at Baton Rouge, 116.6 inches, and the least in 1853, at Fort Yuma in lower California, 1.78 inches.

By analyzing the rainfall statistics of the United States, extending over a series of years,* we ascertain that territorial divisions having the same meteorological characteristics yield similar results, both as to the order of the monthly precipitation, and as to the total annual amount.

Fanning, in his able work on water supply, groups the statistics in the following order :

		Mean Annual Rainfall.
Group 1.	Atlantic sea coast from Portland to Washington.....	43.44
" 2.	Atlantic sea coast, Virginia to Florida.....	47.63
" 3.	Hudson River Valley, Northern and Western New York, Vermont.....	34.99
" 4.	Upper Mississippi, part of Iowa, Minnesota and Wisconsin.....	33.27
" 5.	Ohio River Valley, western Pennsylvania to eastern Missouri.....	40.88
" 6.	Indian Territory and western Arkansas..	38.25
" 7.	Lower Mississippi and Red Rivers.....	51.48
" 8.	Mississippi Delta, Coast of Mississippi and Alabama...	59.12
" 9.	Pacific Coast, San Francisco to Alaska.....	41.49

Taking the mean fall for each month in the year, and plotting it with reference to a horizontal line as unity, representing the mean monthly fall at one-tewlfth of the mean annual, we obtain a type curve for each group representing the fluctuations of the rainfall for each month :

Curve 1.	Group 1.	Average fluctuation of the year.	Maximum rainfall.	Minimum rainfall.
			Month of	
		Pr. cent.		
1	1	40	August.	January or February
2	2	128	1st August.	April and October.
3	3	66	1st July.	1st February.
4	4	109	30th June.	1st February.
5	5	73	1st June.	January.
6	6	91	May.	January.
8	8	75	August.	October.
	9	232	December.	July.

Making application now to the 3d group, representing the Hudson Valley, Vermont, Northern and Western New York, we can test the type curve with reference to this particular locality where the record of the rainfall has been kept since 1826.

We find the fluctuation of the monthly fall during the last fifty years to be 66 per cent., that the rainfall is a maximum in the month of July, and a minimum in February.

If we take the rainfall for each year since 1826, and construct a curve, we represent the wet and dry periods as they vibrate back and forth about the mean of the whole. From such a figure the following facts are noticeable : The years of low rainfall occur more frequently in twos or threes, 1834–5, 1851–2, 1858–59–60, 1864–65–66. These series of low years appear to succeed each other at regular intervals of from ten to eleven years, thus : 1834–5, 1844, 1854, 1864 and 1875 ; that several years of more than mean rainfall are followed by several of less than the average, thus : 1861–62–63 are followed by 1864–65–66 ; that the average rainfall of a series of low years is about eight-tenths of the mean.

Great storms or unusual draughts affect temporarily the annual results, while a series of years will approach closely to the mean.

In the great storm of October, 1869, there fell during forty hours, between 8 and 9 inches, which caused an average annual rainfall to become a maximum. The record at Troy shows in that month a fall of 13.80 inches, as compared with a mean precipitation for that month of 3.57 inches, so at the present writing, the rainfall during the last 60 days has been very slight, and probably this year will be an unusual minimum. As the drainage area with which the engineer has to deal is comparatively limited, the question of storage becomes of great importance.

When we consider, as deduced above, that the period of low rainfall may extend through a term of three or four years, during which time the annual fall will only equal eight-tenths of the mean, it becomes necessary to determine not only the proportion per annum, but the proportion per month which may be made available. The surface and degree of cultivation affect largely the propor-

* Smithsonian Contributions to Science, Vol. XVIII.

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tion of water flowing from any drainage arae, and when possible this should be determined by measuring the amount flowing off and comparing it with the recorded rainfall on the known area. Experiments of this kind are not numerous, but from the record of the drainage of large river and small hill districts in England,* the flow from the Croton and Cochituate basins,† the measurements of the Madison and Eaton Brooks,‡ the following percentages of drainage may be taken as approximately correct:

From mountain slopes or improved rock hills	80 to 90
" woody swampy lands	60 " 80
" undulating pasture and wood-land	50 " 70
" flat cultivated land and prairie	45 " 60

When the area is ample it will be safe in the calculations to take 50 per cent. of the mean annual rainfall as collectable.

Having decided upon the percentage of the annual rainfall which can be collected from the different surfaces, our next step is to ascertain its distribution throughout the year. The average monthly rainfall at Troy, for the last fifty years, divided by one-twelfth of the mean annual fall, will give the ratio of each month, as follows:

Jan.	Feb.	March.	April.	May.	June.
.79	.69	.80	.93	1.06	1.29
July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.35	1.13	1.02	1.19	.96	.82

These ratios may be used in determining approximately the rainfall in any month where the mean annual is known, but they do not represent the amount flowing from a given area. It will be found that when these ratios are the greatest the least amount is collectable, which becomes evident upon consideration, that in July and August the temperature is high, the evaporation greatest, and the percolation into the ground, and the absorption of vegetable life the greatest.

"The analysis of the records of the flow of the average Atlantic coast streams leads to the following approximate estimate of the ratio of the monthly mean rainfall that flows down the streams in each month of the year, in which due consideration of the evaporation from soils and foliage in very dry seasons has not been neglected."*

MONTHLY RATIOS OF FLOW OF STREAMS.

	Ratio of flow.
January	1.65
February	1.50
March	1.65
April	1.45
May	.85
June	.75
July	.35
August	.25
September	.30
October	.45
November	1.20
December	1.60

Here unity equals the mean monthly flow, or one-twelfth the mean annual flow.

We are now able to estimate the quantity which can be collected from a given area not exceeding 100 square miles in extent. Having used as an illustration thus far this city, we will apply the computation to the same locality.

The mean annual rainfall here is 36.15 inches, while as shown in Fig. 6, the series of low year precipitation amounts to about .8 of the mean.

The mean annual flow of the streams from the drainage area, is assumed to be 50 per cent. of the annual rainfall.

$$\frac{36.15 \times 0.5 + 0.8}{12} = 1.205 \text{ inches.}$$

average available rain monthly.

This average, multiplied by the ratios above, gives the depth in inches of available rain flowing in each month, thus:

	Mean monthly Rainfall.		Ratios.		Depth in inches of available Rain flowing Per month.
January	1.205	×	1.65	=	1.98
February	"	×	1.50	=	1.80
March	"	×	1.65	=	1.98
April	"	×	1.45	=	1.74
May	"	×	.85	=	1.02
June	"	×	.75	=	.90
July	"	×	.35	=	.42
August	"	×	.25	=	.30
September	"	×	.30	=	.36
October	"	×	.45	=	.54
November	"	×	1.20	=	1.44
December	"	×	1.60	=	1.92

which quantities have only to be multiplied by the number of acres or square miles in the water shed to determine the amount obtainable.

The fluctuations in the rainfall and in

* Beardmore. † Fanning. ‡ Canal Rep., 1863, 1875.

* Fanning Water Supply.

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the flow of streams as above shown, together with the great variation in the consumption, necessitates, in almost every case, large artificial storage. The present article has exceeded greatly the limits originally intended, and therefore, the question of consumption will not be investigated at this time, but before concluding it will be necessary to consider briefly the question of evaporation and percolation, losses which affect largely the available supply.*

Experiments in this country on the annual evaporation from water surfaces are very limited, but where the depth of water is ten feet and over, a safe estimate of the evaporation will be about 60 per cent. of the annual rainfall in the Eastern and Middle States. In the case of Troy, we should have 36.15 + 60 per cent. = 21.6 inches. 21.6 inches divided by 12 gives 1.8 inches as the mean monthly evaporation.

This mean must be multiplied by the monthly ratios, as in the rainfall and drainage, to obtain the average monthly evaporation.

These ratios are approximately:

	Mean ratio.
January	.30
February	.35
March	.50
April	.80
May	1.45
June	1.70
July	1.85
August	2.00
September	1.45
October	.75
November	.50
December	.35

The monthly evaporation for this locality would then be closely:

	Inches evap.
January	.54
February	.63
March	.90
April	1.44
May	2.61
June	3.06
July	3.33
August	3.60
September	2.61
October	1.35
November	.90
December	.63
Year	21.6

* Evaporation measured on the west branch of the Croton River gave 24.15 mean annual, or about 50 per cent. of the rainfall. J. Jas. R. Croes, Am. Soc. Civ. Eng'rs, N. Y., July, 1874. Also, at Ogdensburgh and Syracuse, N. Y., Salem and Cambridge, Mass., ranging from 49.37 to 56 in. per annum.

From what has been stated it is evident that the evaporation from the land and water surface of the drainage area has already been taken into account in the assumption of only 50 per cent. of the rainfall as flowing in the streams, and this additional loss refers to the reservoir surfaces only.

Collecting the results, we find; the mean annual rainfall being	1.00
The mean annual of low year series	.80
Annual available flow of stream	.50
Annual evaporation from land and consumption by vegetation	.40
Annual evaporation from water surfaces.	.60

In the calculation upon water works, we deal with the monthly ratios as deduced from the above annual, thus:

TABLE OF MONTHLY RATIOS, RAIN FLOW AND EVAPORATIONS.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Ratio average monthly rain	.75	.83	.90	1.10	1.30	1.08	1.12	1.20	1.00	.95	.93	.84
Ratio average M. flow of stream	1.65	1.50	1.65	1.45	.85	.75	.35	.25	.30	.45	1.20	1.60
Ratio M. evap. from water	.30	.35	.50	.80	1.45	1.70	1.85	2.00	1.45	.75	.50	.35

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AMBER.

Translated from "La Nature."

The ancients regarded amber as a precious substance. They made ornaments of it, and engraved upon it the images of their deities. The Egyptians called it *sacal* or *checheleth*. It was one of the three aromas which formed the incense of the Tabernacle. The Philistines called it *sachaleth*, and the Phenicians *secheleth*. The Scythians called it *savium*, the Greeks *electrum*. *Chachal* signifies weeper. Amber, they said, originated in the tears of the sisters of Phaeton, who were transformed into poplars. Homer in the Odyssey calls both amber and an alloy of gold and silver, *electrum*. The palace of Menelaus was ornamented with amber.

The trade of the Phenicians in amber of the north is yet a subject of controversy. Herodotus, in his description of Europe, makes no mention of amber in the northern part.

Tacitus was the first to make mention of the amber of Prussia. It was not obtained from Prussia before the year 500, but from the peninsula of Cimbria, Jutland or the lower Elbe. The amber was carried across the continent to the shores of the Mediterranean. Hatria or Atria, founded by the Pelagians upon the shore of the Adriatic, was the center of commerce of bronze and amber, and was on the highway between occident and orient.

The Assyrians engraved ornamental designs upon amber which they called *electra* or stone of the sun. The Greeks changed this word to *electron*. Thales was the first to discover that amber, when rubbed, attracted light bodies; from this fact, as is well known, we get the word *electricity*. The Roman gladiators often carried amulets of amber, bearing the inscription "I shall conquer."

According to the ancients, amber came from Lydia, where it was formed out of the urine of the Lynx, and it was hence called *Lyncurium*. They knew nothing of its nature nor of its vegetable origin. In Byzantine art we find but few objects made in amber; but during the Middle Ages and throughout the Renaissance it was much wrought; medallions, crucifixes, reliquaries and images of the Virgin being carved in it.

The name amber was brought from the East by the crusaders, who got it from the Arabic wood *ambar*. The Spanish called it *ambrara* and the Italians *ambra*. But these names are less significant than those given by the Romans and the Germans; the former calling it *lapis ardens* and the latter *bernstein*, both names signifying a stone which burns. Modern Greeks call it *berenikenstan*.

After the treaty of Tilsit, there was accumulated at the Louvre a large collection of objects in amber of all shades, and wrought in a great variety of forms. Sicily probably furnished most of the amber to the ancients, just as at present the shore of the Baltic supplies the entire world. Although amber has been found in small quantities elsewhere, it has up to the present time been chiefly furnished from these two centers.

The theory of the origin of amber is the following: During the eocene epoch the present bed of the Baltic was occupied by an immense forest, which extended over most of the northern part of the continent.

In dredging at the bottom of the sea, there is found, at two meters' depth, thirty-two species of cone-bearing trees. These trees exuded a gum, which having been subjected to long continued pressure in the earth has become amber. The *Pinus succinus* has produced the larger proportion of it. More than twelve hundred species of fossils have been found enclosed in it. When the resin flowed from the tree it exhaled an odor which attracted flies, and these in turn drew the spiders, who, spun webs to catch them. Reptiles, pursuing their prey, were entrapped by it, and a fresh layer of resin flowing over them, they were preserved for all time. The gum remained sometines fast to the tree, but it frequently dropped upon the ground and enveloped shells, minerals, twigs, mosses and drops of salt water.

Amber is mined from slight depths in

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the earth,* and is gathered by divers from the bottom of the sea. It is at times worked up on the shores of the Baltic during storms. Amber is the property of the crown. In Prussia no one can mine it on his own property without purchasing the privilege from the government, the income from this source amounting to 600,000 francs a year. One company that employs several steamboats for dredging along the shores of Konigsberg, pays about 400 thalers per day for the privilege.

The production of amber in 1874 was 175,000 kilogrammes, in masses of all qualities and of all sizes, sent to all parts of the world. The finer qualities are employed in the manufacture of mouthpieces for pipes, cigar-holders, and table and mantel ornaments of all kinds. A chandelier of amber made by Hartman, exhibited at Vienna, was bought by the Emperor of Russia for 75,000 francs.

True amber is distinguished from substances which somewhat resemble it, especially copal, by the following characters:

1st. Copal is yellow, of a more or less deep tint, but uniform throughout, and has upon its surface yellow points resembling crystallized sulphur. Amber, on the contrary, in a fragment of 12 centimeters' length will always exhibit a variation of shade.

2d. If a fragment of amber be rubbed with the finger in the palm of the hand for a few seconds, it will exhale a strong aromatic odor. Copal and the other imitations of amber have not this property.

3d. By long exposure to the air, amber sometimes parts with its essential oil, and loses its characteristic aspect. If the surface be scraped with a knife, the dust formed is heavy and falls; copal, treated in the same manner, yields a fine dust that floats in the air.

4th. Amber may be bent by smearing it with tallow, and heating it for some minutes, taking care to heat it most strongly at the places where it is expected to yield the most. The imitations will not bend.

5th. Amber is harder than any of its imitations. It is with difficulty scratched by the finger nail. Copal yields easily, especially to repeated efforts.

6th. Amber may be cut, sawed, rasped or polished, but cannot be cemented or soldered as can its imitations.

7th. To prepare varnish, copal is melted in a copper vessel over a brisk fire. At 100° C. the water contained in it forms considerable steam; the copal melts, preserving its yellow color. Amber requires a temperature of 400° to fuse it, at which point it blackens and yields an overpowering odor.

If 33 per cent. of linseed oil be added to amber it will melt at 150°.

8th. The density of amber is 1.09 to 1.11. The density of copal is 1.04, and of some false amber, 1.05.

9th. Amber yields, upon distillation, needle-shaped crystals of succinic acid. The different copals do not.

When used for cigar-holders, false amber fuses easily; copal cracks while amber resists the heat.

The chemical composition of amber is, according to Schrotter,

Carbon 78.82.
Hydrogen 10.25.
Oxygen 10.90.

*The only locality where amber is produced from underground works is at Palmnicken, on the Baltic coast. The stratum producing it is the so-called "blue earth," a loose sandstone of a bluish color, from included glauconite grains, when fresh, but weathering to a greyish green, is the lower member of the marine tertiary formation of the district. The thickness varies from 8 to 28 feet, the lower part of 7 to 11½ feet alone being worked. An area of about 160 acres has been proved by shafts and levels, the depth below the surface being about 108 feet, or 46 feet below the level of the sea. The ground being easily excavated by pick and shovel, the advance of the levels is at the rate of 3½ to 7 feet in the shift of twelve hours; but for the same reason considerable expenditure of timber is necessary to secure the sides of the workings. The levels are timbered with complete door-frame sets, at intervals of 3½ feet from center to center, the roof and sides being lined with inch planks. Great care must be exercised in securing the working faces, which, when left to themselves, even for a short time, readily give way. It is even found necessary to board up the ends of the levels on leaving them at the change of shift. The section of the levels varies with the workable thickness of the bed from 5 to 12 feet in height; the breadth is generally 4½ feet.

For the brilliant white enamel often applied to fine cards and other purposes, the following formula is given: For white, and for all pale and delicate shades, take 24 parts by weight of paraffine, add thereto 100 parts of pure kaolin (China clay), very dry, and reduced to a fine powder. Before mixing with the kaolin the paraffine must be heated to fusing point. Let the mixture cool, and it will form a homogeneous mass, which is to be reduced to powder, and worked into paste in a paint mill with warm water. This is the enamel ready for application.

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EXPERIMENTAL INVESTIGATIONS OF THE RESISTANCE OF FLUES TO COLLAPSE.

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Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

1. CRUSHING AND COLLAPSING OF TUBES.—A hollow cylinder exposed to an external fluid pressure experiences a circumferential thrust, which has the greatest intensity at the inner surface of the cylinder. When the thickness of the cylinder is small, relatively to its diameter, the circumferential thrust may be considered, without a sensible error, as being of equal intensity throughout the wall of the cylinder, and the crushing pressure will be given with sufficient accuracy for practical purposes by the following formula, viz :

$$p=\frac{2tcC}{d} \qquad (1)$$

where p=pressure in pounds per square inch, t=thickness of cylinder in fractions of an inch, d=diameter of cylinder in inches, and C=modulus of rupture for crushing of the material.

This formula applies only to the case of a tube having an accurately circular cross section, and constructed throughout of perfectly homogeneous material, which is strained equally at every portion of its wall. A tube strained by an external fluid pressure may be regarded as being in a state of unstable equilibrium, because deviations from the circular form, either existing originally in the tube or produced by the conditions under which the pressure is applied, tend to increase in an increasing ratio with the pressure till the tube gives way by collapsing. In practice the cross section of boiler flues is never exactly circular, nor is their material ever perfectly homogeneous, and they always give way by collapsing at a pressure far below that given by formula (1). Deviation from circularity and imperfect homogeneity in boiler flues are variable and uncertain elements, and this fact is sufficient to account for the discordant results obtained in many experiments on the collapse of flues under apparently equal conditions. To obtain results of real practical value, it is important that the dimensions and the construction of experimental flues should be, as nearly as possible, such as are actually used in steam boilers; and the experiments should be specially directed to the determination of the quantity of the weakening effect of such distortions as may obtain under various conditions of practice.

2. EXPERIMENTS ON THE COLLAPSE OF TUBES.—The earliest, best known, and most extensive experiments on the resistance of tubes to collapse were made by William Fairbairn, and were first described by him in a paper read before the Royal Society in 1858. (See "Philosophical Transactions," 1858, also "Useful Information for Engineers," Vol. II.)

The apparatus used by him consisted of a cast-iron cylinder 8 feet long, 28 inches in diameter and 2 inches thick, having a removable cover at each end. The cylinder communicated with a force pump. The pressure within the cylinder was measured by two spring gauges, and a safety valve did not permit the pressure to rise above 500 pounds per square inch. During the experiments this cylinder was placed upright in a pit.

The tubes experimented upon consisted, in most cases, of a single plate, 0.043 inch thick, bent to the cylindrical form upon a mandril, and riveted and brazed at the joint to prevent leakage. The ends of these tubes were riveted and brazed to rigid cast-iron discs. The diameters of these experimental tubes were 4″, 6″, 8″, 10″, and 12″, and their lengths, between the cast-iron ends, ranged between 19 inches and 60 inches. A pipe, 2½ inches in diameter, which passed through the upper cover of the cast-iron cylinder and was secured to it by nuts, placed the interior of the experimental tube in communication with the outer air. This pipe served also the purpose of bracing the upper disc of the

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tubes; the lower disc was braced by a rod secured to it and to the lower cover of the cast-iron cylinder.

A few experiments were made in which the cast-iron ends of the tubes were not braced, in order to determine whether the tension produced in the tubes by bracing them had any influence on their resistance to collapse. But the results obtained were conflicting and were not regarded as conclusive by Fairbairn.

Some of the experimental tubes tested by Fairbairn were thicker than 0.043 inch, viz:

One tube (*a*) 18¾ inches in diameter and 61 inches long, and consisting of a single sheet with a lap-joint, was made of plate iron 0.25 inch thick. It collapsed at a pressure of 420 pounds.

Two tubes, both 9 inches in diameter and 37 inches long, were made of plate-iron 0.14 inch thick. One (*b*) had a longitudinal butt-joint with an outside covering plate, and collapsed at a pressure of 378 pounds. The other one (*b*) had a longitudinal lap-joint, and bore only 262 pounds.

An iron flue (*c*), consisting of three courses with lap-joints, the longitudinal seams breaking joint, was made of plates 0.125 inch thick. Its diameters were 14½ and 14$\frac{11}{16}$ inches, its extreme length 60½ inches; the ends were of sheet-iron ¼ inch thick. The rivets, ¼ inch in diameter, were spaced 1¼ inches apart. This tube collapsed at a pressure of 125 pounds.

An iron flue (*d*), 15 inches in diameter and 0.125 inch thick, consisted of three rings connected by flanges with a plate-iron diaphragm between them. The length of the two outer rings was 21¼ inches, that of the middle ring was 17 inches. The rivets began to leak at 150 pounds, and after being re-caulked, one of the outer rings collapsed at 146 pounds. This experiment was rejected by Fairbairn, who suspected that the tube was originally defective.

A steel flue (*e*), having the same dimensions and constructed in like manner as flue (*d*), collapsed at 220 pounds in the middle ring. This flue was slightly elliptical, the diameters being 15$\frac{3}{16}$ inches and 15⅝ inches.

Two experiments were made with elliptical tubes, which showed the weakening effect produced by a deviation from the circular form.

From the foregoing experiments Fairbairn deduced the following empirical formula, viz.:

$$p = 9{,}675{,}600\frac{t^{2.19}}{ld} \qquad (2)$$

where the notation is the same as in formula (1), and l = length of tube in inches.

In the year 1874 experiments were made at the Navy Yard, Washington, D. C., with two large cylindrical boiler flues. (See Shock, "Steam Boilers," p. 113).

The apparatus used for this purpose consisted of a cylindrical shell 63 inches in diameter, constructed of plate-iron ⅝ inch thick; the experimental flues were riveted to flanges within this shell.

For the first experiment a cylindrical flue (*f*) 76½ inches long and 54 inches in inside diameter, was made of ¼ inch boiler iron. It consisted of two rings connected by an interior butt-strap 7¾ inches wide and ¼ inch thick. Each ring was formed of two plates with butt-joints, having interior butt-straps 7¾ inches wide and ¼ inch thick. The longitudinal seams of the two rings broke joint. All seams were double riveted. The unsupported length of the experimental flue (measured between the inner edges of rivet holes in flanges) was 71¼ inches.

One of the rings of this flue collapsed at a pressure of 105 pounds. The bulged part was pressed out and shored up, and the pressure was again applied. This time collapse took place in the other ring at a pressure of 120 pounds. The operation of forcing out and shoring up the bulge was repeated several times, the tube becoming stiffer each time. At the fifth trial collapse took place at a pressure of 186 pounds. It was found that the sheet which collapsed first was slightly less in thickness than ¼ inch, and that the flue was slightly oval, the larger diameter being 54¼ inches, and the smaller diameter 53¾ inches.

A second flue (*g*) was made of ¼ inch boiler iron, the sheets having been accurately gauged before fitting them. This flue consisted likewise of two rings, 38 inches and 39 inches long over all respectively, which were connected by flanges with a ring $\frac{11}{16}$ inch thick between

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them, as in the Adamson joint. This flue was found to be perfectly cylindrical, having an internal diameter of exactly 54 inches. One of the rings collapsed at a mean pressure of 133.3 pounds, as indicated by three spring gauges. The bulged part was shored up and a second trial was made, when the other ring collapsed at a mean pressure of 130.6 pounds.

Experiments were made in March, 1878, by the Leeds Forge Company, England, with a plain cylindrical and a corrugated furnace flue, to test their relative strength when exposed to a collapsing pressure. (See "Engineering," Vol. XXV, pp. 245–260).

The plain cylindrical flue (*h*) was made of two iron plates $\frac{5}{8}$ inch thick, of unequal width, the narrower plate being about 24 inches wide. These plates were lap-welded, the welded parts being hammered down to the thickness of the adjacent portions of the plates. The actual thickness of the plates varied from 0.36 to 0.40 inch. The flue had an outside diameter of about $37\frac{1}{4}$ inches, and a length of 84 inches, with a turned collar in addition at each end, welded on, making the length $97\frac{1}{2}$ inches over all.

The test vessel was a wrought-iron cylinder, about 3 inches larger inside than the experimental flue, and strengthened with five welded rings $5'' \times 3''$, bored and shrunk on. The ends were formed by cast-iron rings, tied to each other by long bolts outside the test vessel, and bored to fit the turned ends of the flues, with a groove to receive a cupped leather packing ring. This arrangement allowed the flue to expand or contract freely.

On testing the flue with straight edges, it was found to have prominences from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch high. Two of these points (marked *a*) at a distance of about four-tenths the length of the tube from one end, were selected for measuring the horizontal and vertical diameters which were found to be 36.65 inches and 37.20 inches respectively. A slight difference in the horizontal and vertical diameters was also found near the other end, where points were selected for measurements during the trial. The pressures were raised by increments of 50 pounds at first, and of 25 pounds afterward, and were taken off again after each increase. At 200 pounds pressure the flue began to come down like a blister, about 5 inches in diameter, on the top of the flue at the point *a* of the original prominence. The pressure began to fall at first slowly, then quickly, until it reached 50 pounds, when the swelling had extended 24 inches by 12 inches by 18 inches deep. The collapse took place in the narrow plate between the two welds, where the thickness was fully 0.375 inch. It was remarkable how slight were the indications of weakness preceding the collapse; a total deflection and permanent set of 0.04 inch at the point *a* being the only sign.

According to Fairbairn's formula (2), this flue should have borne about 360 pounds pressure, while it actually bore but little more than one-half that pressure. Although the tube was not accurately circular, the irregularities of form were not greater than are common in welded flues, and were less than in ordinary riveted lap-jointed flues. It may be assumed that the close proximity of the two welds was a source of weakness. It is also probable that the flue would have resisted a greater pressure, if the ends had been rigidly secured, instead of being merely stiffened by stout rings and otherwise left free to move.

In addition to the foregoing experiments, a few cases of the collapse of tubes are recorded by different writers, in which the conditions under which collapse took place were sufficiently well known to make the data valuable for comparison.

Fairbairn gives two examples of new boilers in which the flues became oval during the application of the hydraulic test pressure. (See "Philosophical Transactions," 1858). The flues (*k* and *l*) were 42 inches in diameter, $\frac{5}{8}$ inch thick, and 35 feet and 25 feet long respectively. The longer flue (*k*) became oval at a pressure of 97 pounds, and the shorter flue (*l*) at a pressure of 127 pounds.

An experiment made by Mr. Alfrey of the firm Humphreys, Tenant & Co., is cited by W. C. Unwin in a paper on the "Resistance of Boiler flues to Collapse," contained in the "Proceedings of the Institution of Civil Engineers," Session 1875–76, Part IV.). The flue (*m*) was old; originally $\frac{5}{8}$ inch thick, it had been reduced to nearly $\frac{5}{16}$ inch by corro-

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sion. There were four longitudinal lap-joints in the circumference of the flue, and four circumferential lap-joints in its length. The diameter of the flue was 33½ inches, its length 360 inches, its thickness 0.34 inch. It collapsed at a pressure of 99 pounds over an arc of about one-eighth of its circumference, the collapsed part extending about one-half of the length of the flue.

An experiment is recorded in Julien et Bataille, "Machines à Vapeur," p. 240. The flue (*n*) had longitudinal and circumferential joints. Its diameter was 7.87 inches, its length 276 inches, and its thickness 0.157 inch. It collapsed at a pressure of 110 pounds.

3. Formula Deduced from the Foregoing Experiments by Different Writers.—Fairbairn thought that the results of his experiments warranted the conclusion that the resistance of cylindrical tubes to collapse varies in the inverse ratio of their diameter and length. In deducing a formula from his experiments he starts with the assumptions that the product of the collapsing pressure, per square inch, into the length and diameter of similar tubes of equal thickness is a constant quantity, and that the resistance of thin tubes to collapse follows the same law as the resistance of thin iron plates to crumpling, which varies directly as a certain power of their thickness; the number indicating this power has been found to lie between 2 and 3.

Selecting twenty experiments with tubes having a thickness of 0.043 inch, Fairbairn deduces from their results a mean value for the expression pld. It is, however, to be observed that this value varied in many cases greatly for the several tubes, and that (with one exception, viz., the 8-inch tubes) the mean value of pld for each set of tubes of equal diameter decreased as the diameter of the tubes increased, but not in a regular ratio. The greatest discrepancy existed in the results of the experiments with 12-inch tubes.

Introducing the mean value of the expression pld into an equation of the form $\frac{pld}{p_1 l_1 d_1} = \left(\frac{t}{t_1}\right)^x$ Fairbairn determines the value of the exponent x from the three experiments marked (*a*), (*b*), (*c*), in Section (2). The three values of x thus found were 2.23, 2.14 and 2.16; and taking 2.19 as the mean of these values, he uses this number as the exponent of t in his equation. In this manner he gets formula (2), viz.:

$$p = 9{,}675{,}600\frac{t^{2.19}}{ld}.$$

Fairbairn says that this "is the general formula for calculating the strength of wrought-iron tubes subjected to external pressure, within the limits indicated by the experiments; that is, provided that their length is not less than 1.5 feet, and not greater probably than 10 feet." It is, however, to be observed that the higher limit of length is arbitrarily fixed, since none of the experimental tubes exceeded 61 inches in length.

Fairbairn states that a closer approximation to the experimental results is given by the formula

$$p = 9{,}675{,}600\frac{t^{2.19}}{ld} - 0.002\frac{d}{t} \qquad (3)$$

which allows for a slight deviation from the circular form owing to the thinness of the plates.

For elliptical flues the value $\frac{2a^2}{b}$ is to be substituted for d in formula (2), where a is the greater, and b is the lesser semi-axis of the ellipse.

He recommends the use of the simpler formula

$$p = 9{,}675{,}600\frac{t^2}{ld} \qquad (4)$$

saying that for thick tubes of considerable diameter and length, this formula may be regarded as sufficiently accurate for practical purposes. It is easily seen that, by substituting the exponent 2 for 2.19, the value of p will be *increased* for thicknesses less than one inch, and *decreased* for thicknesses greater than one inch. The increase will amount to 70 per cent. when t is $\frac{1}{16}$ inch, 20 per cent. when t is $\frac{8}{9}$ inch, and 0 per cent. when t is 1 inch.

R. Wilson makes the following observations regarding Fairbairn's formula, viz.:

"Its application is limited to wrought-iron tubes above a certain length, for it can easily be shown that, if we take the crushing (crippling) strength of the ma-

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terial at 12 tons per square inch, the number 15 multiplied by the thickness in inches of the tube will give the length in feet at which the crushing (crippling) strength of the tube and its collapsing strength, according to Fairbairn's rule, are equal, and any further reduction of the length will not give the increase of strength as it should do if the formula were correct. . . .

"It is probable that with ordinary tubes of the above lengths, a collapsing pressure over one-half the crushing (crippling) pressure will never be attained. . . .

"If Fairbairn's formula is worth anything at all, we shall gain nothing in collapsing resistance to hydraulic pressure by making $\frac{5}{8}$ inch thick tubes in shorter lengths than 11 feet, seeing that this is the length given by the rule (viz. formula 2), at which the collapsing strength is half the crushing (crippling) pressure . . . The greater the thickness of the tube in proportion to the diameter, or the stiffer the tube the more will the strengthening rings tend to bring the collapsing pressure up to the crushing (crippling) pressure. A consideration of the resisting powers of the strengthening rings themselves should also not be omitted in an investigation of this matter at the high pressures we are assuming. For a $\frac{5}{8}$ inch thick tube strengthening rings, at 3-feet lengths over the fire, still serve a very useful purpose in keeping the tube in shape in the event of overheating, and in restricting the amount of distortion in the event of collapse, and should always be employed here." (See *Engineering*, June 2, 1876).

Fairbairn's formula (4) has been generally accepted as the basis of rules for ascertaining the strength of boiler flues. In some cases, however, limits are fixed to its application by a supplementary formula of the form of equation (1).

Lloyd's Register contains the following formula for the strength of circular boiler flues, viz.:

$$P=\frac{89{,}600t^2}{Ld}. \qquad (5)$$

* The English Board of Trade prescribes the following formula for circular flues, when the longitudinal joints are welded, or made with riveted butt-straps, viz.:

$$P=\frac{90{,}000t^2}{(L+1)d} \qquad (6)$$

For lap-joints and for inferior workmanship the numerical factor may be reduced as low as 60,000.

The rules of Lloyd's Register as well as those of the Board of Trade prescribe further, that in no case the value of P must exceed the amount given by the following equation, viz.:

$$P=\frac{8000t}{d} \qquad (7)$$

In formula (5), (6), (7), P is the highest working pressure in pounds per square inch, t and d are the thickness and diameter in inches, L is the length of the flue in feet measured between the strengthening rings, in case it is fitted with such. Formula (5) is the same as formula (4), with a factor of safety equal to $\frac{1}{5}$. In formula (6) the length L is increased by 1; the influence which this addition has on the value of P is, of course, greater for short tubes than for long ones. By an inspection of column VI of the subjoined table, it will be seen that the limit fixed by formula (7), for formulæ (5) and (6) is by no means too low.

Grashof selected twenty-one of Fairbairn's experiments (seventeen of which were on tubes 0.043 inch thicker, and four on tubes from $\frac{1}{8}$ to $\frac{1}{4}$ inch thick), and deduced from them the following formula, viz.:

$$p=24{,}481{,}000\frac{t^{2.315}}{ld^{1.278}} \qquad (8)$$

This formula agreed, however, better with the results of the experiments with thin tubes than of those with thicker ones; Grashof devised, therefore, a second formula, which gives a close agreement with the four experiments on tubes from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch thick, viz.:

$$p=1{,}033{,}620\frac{t^{2.061}}{l^{0.564}d^{0.889}}, \qquad (9)$$

where the notation is the same as in formula (2). (See "Theorie der Elasticitat und Festigkeit," von Dr. F. Grashof, p. 328.)

Nystrom has deduced from Fairbairn's

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experiments the following formula for the collapsing strength of flues, viz.:

$$p=\frac{4\,T\,t^2}{d\sqrt{L}} \qquad (10)$$

where p, t and d have the same meaning as in formula (2), L is the length in feet, and T is the tensile strength of the metal in pounds per square inch.

If we assign to T the value 50,000, and express the length of the flue in inches, equation (10) assumes the following form, viz.:

$$p=692{,}800\,\frac{t^2}{l^{0.5}d} \qquad (10a)$$

which is more convenient for comparison with formula (9.) Nystrom considers the factor of safety $\frac{1}{4}$ sufficient in applying his formula. (See "A new Treatise on Steam Engineering," by J. W. Nystrom, p. 106).

Formulæ (2), (5), (8), (9) and (10) have the common defect that they make the collapsing pressure decrease indefinitely with increase of length and *vice versa*. M. Love has deduced from Fairbairn's experiments an equation of a different form, which, reduced to English measures, is as follows, viz.:

$$p=5{,}358{,}150\,\frac{t^2}{ld}+41{,}906\,\frac{t^2}{d}+1{,}323\,\frac{t}{d} \qquad (11)$$

where the notation is the same as in formula (2). Prof. W. C. Unwin says, regarding this formula: "It is based to a certain extent on theoretical considerations bearing on the probable limit of decrease of collapsing pressure with increase of length, and it no doubt represents very closely Fairbairn's experiments."

Unwin, who had been associated with Fairbairn in making the experiments described in section (2), has published a re-investigation of them in the "Proceedings of the Institution of Civil Engineers," Vol. XLVI., Session 1875–76, Part IV., of which the following is an abstract:

He shews first that in the experiments with thin tubes, which had a uniform thickness of 0.043 inch, the originally circular tubes bent during collapse into figures consisting of acres of alternately convex and concave curvatures, and that the number of arcs increased as the ratio of length to diameter decreased.

Considering a strip of a tube 1 inch wide, the total uniformly distributed load on one arc of such a strip is $p\lambda$ pounds, when t is the length of the arc; and the resistance to bending is given by the equation

$$p\lambda=\tfrac{4}{3}f\frac{t^2}{\lambda},\ \text{and}\ p=\tfrac{4}{3}f\frac{t^2}{\lambda^2} \qquad (12)$$

Consequently the collapsing pressure necessary to produce bending varies inversely as the square of the length of the arcs into which the tube divides; and the strength of the tube must depend on the number of arcs into which the tube divides. From the results of 19 experiments with thin tubes Unwin finds the equation

$$\lambda=0.6375\,l^{0.45}d^{0.08} \qquad (13)$$

which gives the best average value for the length of the arcs into which the tubes divided during a collapse.

Unwin assumes that the metal of the flue is in the same condition as a straight column of the length πd, subjected to a compression of the intensity

$$T=\frac{pdb}{2} \qquad (14)$$

where b is the length of a slice of the flue, and d its diameter. He then applies the laws of resistance of long columns to the investigation of the strength of flues. According to Euler's theory we have

$$T=\pi^2\frac{IE}{\lambda^2} \qquad (15)$$

where I is the moment of inertia of the section of the column about an axis, through its center of figure, and perpendicular to the plane of bending; E is the modulus of elasticity of the material; T is the greatest thrust consistent with stability. For a rectangular section,

$$I=\frac{bt^3}{12};\qquad \text{then}$$

$$T=\frac{\pi^2E}{12}\,\frac{bt^3}{\lambda^2} \qquad (16)$$

Putting E=28,500,000 we have

$$T=23{,}440{,}000\,\frac{bt^3}{\lambda^2}; \qquad (17)$$

and combining equations (14) and (17), we get

$$p=\frac{46{,}880{,}000\,t^3}{d\lambda^2} \qquad (18)$$

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Introducing into this equation the value of $t=0.043$, we find

$$\lambda=\frac{61.05}{\sqrt{pd}} \qquad (19)$$

Combining equation (19) with equation (13), we obtain for the collapsing pressure of tubes 0.043 inch thick, the following formula, viz.:

$$p=\frac{9170}{l^{0.9}\ d^{1.16}} \qquad (20)$$

Fairbairn's formula for the same tubes, is

$$p=\frac{9838}{l\,d} \qquad (21)$$

which is not widely different, though obtained in an entirely different manner.

Unwin next defines the limits of length and thickness within which the formula is applicable. He finds, $l_{\max.}=6.7\,d^2$ nearly; $l_{\min.}=4468\,\frac{t^{2.22}}{d^{0.18}}$. The two limits coincide when $t=\frac{d}{19}$. For greater values of t the formulæ cease to be applicable.

Assuming that the preceding investigations indicate that the collapsing pressure of tubes is given by an equation of the form

$$p=c\frac{t^n}{l^{0.9}\ d^{1.16}},$$

and, taking the experiments on thin tubes as a starting point of the comparison, Unwin deduces values of the factor c and the exponent n from a number of experiments with thicker tubes, combining the results obtained with tubes of similar construction.

From two experiments with tubes made with a *longitudinal lap-joint*, [marked (a) and (b), in section 2], he deduces the formula

$$p=7{,}363{,}000\frac{t^{2.1}}{l^{0.9}d^{1.16}} \qquad (22)$$

From one experiment with a tube having a *longitudinal butt-joint*, [marked (b) in section 2], he gets the formula

$$p=9{,}614{,}000\frac{t^{2.21}}{l^{0.9}\ d^{1.16}} \qquad (23)$$

From five experiments with tubes having *longitudinal and circumferential joints* [marked (c), (k), (l), (m) and (n), in section 2], he derives the formula

$$p=15{,}547{,}000\frac{t^{2.35}}{l^{0.9}\ d^{1.16}} \qquad (24)$$

In order to make the latter formula convenient for arithmetical calculations, he gives it the form

$$p=15{,}547{,}000\,\frac{t^2}{ld}\cdot\frac{\alpha}{\beta\gamma} \qquad (24a)$$

where $\alpha\ \beta\ \gamma$ are variable co-efficients, the values of which, corresponding to certain values of t, l and d, are given by him in a table adjoined to his investigation.

Unwin says, regarding these formulæ: "It will be seen that the indices of the thickness do not differ more than would be anticipated from Hodgkinson's value. It is believed that the separation of the experiments, here adopted, into sets of similar experiments leads to more reliable results than the mixing up of heterogeneous experiments to obtain average values of constants. In applying these formulæ to practical cases, it ought to be borne in mind that slight deviations from the circular form may greatly affect the value of λ, and much reduce the strength of the flue."

Theodore Belpaire has made an attempt to develop a formula for the strength of flues from experimental data, from which the variable and uncertain element of strength due to circularity of form has been eliminated. He starts with the idea that flues derive their main strength from the rigid fastenings of their ends. Considering the flexure of a narrow strip of a tube cut parallel to its axis, he finds that the bending forces are so insignificant that they may be neglected without sensible error; and he bases, therefore, his investigation on the equation giving the greatest shearing forces which exist at the rigidly secured ends of the loaded strip, viz.:

$$S=\frac{p\,l}{2\,t} \qquad (26)$$

The highest value of S consistent with stability is to be deduced from experimental data. Belpaire rejects all experiments with circular flues, and uses those made with elliptical ones, because in the latter cases the relation existing between the strength and the form of the transverse section can be deduced with some degree of certainty.

Calling D the greater and X the lesser

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diameter of the ellipse, he represents its eccentricity by

$$e=\frac{D-X}{D} \qquad (27)$$

S is evidently a function of the eccentricity, and may be expressed with sufficient accuracy by an equation of the form

$$S=a+Be+Ce^2. \qquad (28)$$

Since the resistance to flexure approaches zero, and consequently. S=O, when E=1, and since, on the other hand, S=a maximum, when e=0, the equation (28) can be put under the following form, viz.:

$$S=A\,(1-e^2.) \qquad (29)$$

S (and consequently A) is likewise a function of $\frac{t}{d}$, and an approximate value for A may be deduced from an equation of the form

$$A=m+n\left(\frac{t}{d}\right)+q\left(\frac{t}{d}\right)^2 \qquad (30)$$

Since S=0, when $\frac{t}{d}=0$, we must make m=0. Introducing this value into equation (30), and combining equations (29) and (30) we get the equation

$$S=\left\{n\left(\frac{t}{d}\right)+q\left(\frac{t}{d}\right)^2\right\}(1-e^2) \qquad (31)$$

Belpaire deduces values for n and q from two experiments by Fairbairn on elliptical tubes. Introducing the values thus found into equation (31), and making e=0, he gets the following expression for S applicable to tubes of a circular cross-section, viz.:

$$S=1{,}713{,}576\left(\frac{t}{d}\right)-28{,}446{,}200\left(\frac{t}{d}\right)^2 \qquad (32)$$

Introducing this value of S into formula (26), we get

$$p=3{,}427{,}152\frac{t^2}{ld}-56{,}892{,}400\frac{t^3}{ld^2} \qquad (33)$$

Applying this formula to a number of examples of tubes collapsed under known conditions, Belpaire finds that the actual collapsing pressures were from 1.05 to 4.15 times as great as the pressures given by formula (33). These variations he ascribes to the influence of the uncertain elements of stiffness, circularity of form and homogeneity of material, which, he avers, should not be allowed to influence a formula of this kind. Since, however, all tubes derive more or less additional strength from these causes, he considers one-quarter a sufficiently large factor of safety in proportioning flues by means of formula (33). (See "Note sur la résistance des tubes pressées de l'extérieur," par Théodore Belpaire, in "Annales du Génie civil," Mars, 1879).

Equation (33) may be written as follows, viz:

$$p=3{,}427{,}152\frac{t^2}{ld}\left(1-16.6\frac{t}{d}\right) \qquad (33a)$$

The factor $\left(1-16.6\frac{t}{d}\right)$ becomes zero, and consequently p=0, when $16.6\frac{t}{d}=1$, or $d=16.6\,t$. This indicates that the formula is, at best, applicable only within certain limits, which, however, have not been determined.

D. K. Clark, in his "Manual of Rules," etc,, p. 696, gives the dimensions of six flues, selected from the reports of the Manchester Steam-Users Association. 1862–69, which collapsed while in actual use in boilers. These flues varied from 24 to 60 inches in diameter, and from $\frac{3}{16}$ to $\frac{8}{8}$ inch in thickness. They consisted of rings of plates riveted together, with one or two longitudinal seams, but all of them unfortified by intermediate flanges or strengthening rings. At the collapsing pressures the flues experienced compressions ranging from 1.53 to 2.17 tons, or a mean compression of 1.82 tons per square inch of section. From these data Clark deduced the following formula "for the average resisting force of common boiler flues," viz :

$$p=t^2\left(\frac{50{,}000}{d}-500\right) \qquad (34)$$

where p is the collapsing pressure in pounds per square inch, and d and t are the diameter and thickness expressed in inches.

It is assumed that the flues are not strengthened by rings. The influence of length on the strength of flues Clark calls an uncertain element; it is, however, a very important one, as proven by Fairbairn's experiments, and for this reason the formula is not generally applicable.

The following table contains the data of all experiments on the collapse of flues having thickness of one-eighth inch

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and more, of which a reliable record could be obtained, and which are described in section 2 of this article; also the collapsing pressures calculated by means of the different formulæ, of which an account has been given. In comparing the calculated with the actual collapsing pressures, for the purpose of estimating the reliability of the several formulæ, it is, of course, necessary in each case not to take into consideration those experiments from which the formula was deduced.

In Fairbairn's formula (2) the index number of the power of t was deduced from the results of experiments Nos. 1, 2 and 6. Leaving these experiments out of consideration, only one experiment, viz., No. 11, shows a tolerably close agreement between the actual and the calculated collapsing pressures; all other experiments give too large a value for flues having a length less than 60 inches, and too small a value for flues having a length of 276 inches or more.

Fairbairn's approximate formula (4) gives in every case a larger value for the collapsing pressure than formula (2), as previously explained. It is easily seen that the close agreement between the actual and calculated results in the case of experiments Nos. 9 and 10 is purely accidental.

Grashof's formula No. (9) gives in every case much too high a value of p, except in experiments Nos. 1, 2, 5 and 6, from which the formula was deduced.

Nystrom's formula (10) was deduced from Fairbairn's experiments, but it is not stated which of them were used. As in no case the tensile strength of the metal of which the experimental flues were made has been recorded, an average value of T=50,000 in the case of iron flues, and of T=70,000 in the case of the steel flue, has been assumed. On the whole, this formula gives a closer agreement of the calculated with the actual collapsing pressures in experiments on flues of every description than any of the other formulæ.

Love's formula (11) gives in every case too large a value, probably because it was deduced mainly from Fairbairn's experiments with very thin tubes.

Unwin's formulæ (22), (23), (24), applied to other experiments than those from which they were deduced, give too large results, except in the case of No. 11, where the agreement is tolerably close.

Experiments Nos. 4 and 5 were rejected by Fairbairn and Unwin, but perhaps not on sufficient grounds. Nystrom's formula (11) agrees quite well with the results of these experiments.

Belpaire's formula (33) gives in only one case a close agreement with the actual results of the experiments; and the degree of agreement varies widely in the other cases.

4. Insufficiency of the Above-Described Experiments.—It will be noticed that many of the formulæ given in the previous section, though deduced mostly from the same set of experiments, and being similar in form, assign very different values to the influence of length, diameter and thickness of tubes on their resistance to collapse, and that most of them give very discordant results.

The differences in the two formulæ, (8) and (9), deduced by Grashof from Fairbairn's experiments, illustrate plainly the fact that the numerous experiments on very thin tubes are of relatively little value for determining the strength of flues used in steam boilers. In fact, all those formulæ which are based principally upon the experiments with tubes 0.043 inch thick, are very defective. This remark applies specially to Fairbairn's formula (2), to Love's formula (11), and also to Unwin's formulæ (22), (23) and (24). Unwin recognized the fact that it was hazardous to apply to thick tubes the rules relating to the influence of length and diameter on the strength deduced from very thin tubes; but he was compelled to do so by the paucity of available experiments. He derived the numerical factor and the index number of t in formula (22) from *two* experiments, those in formula (23) from *one* experiment, and those in formula (24) from *five* experiments, on tubes from $\frac{1}{8}$ inch to $\frac{5}{8}$ inch thick. There are not a sufficient number of experiments extant to test fully the value of his formulæ.

It should be especially noticed that *not a single* experiment has been made on tubes representing exactly the ordinary construction and dimensions of cy-

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TABLE SHOWING DIMENSIONS, AND ACTUAL AND CALCULATED COLLAPSING PRESSURES OF FLUES.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	
							Calculated Collapsing Pressure.														
Number of experiment.	Length in inches. l	Diameter in inches. d	Thickness in inches. t	Ratio of length to diameter. $\frac{l}{d}$	Crushing pressure in pounds per square inch of section. $\frac{pd}{2t}$	Actual collapsing pressure in pounds per square inch. p	Fairbairn's formula (2.) p_2	Ratio. $\frac{p_2}{p}$	Fairbairn's formula (4.) p_4	Ratio. $\frac{p_4}{p}$	Grashof's formula (9.) p_9	Ratio. $\frac{p_9}{p}$	Nystrom's formula (10.) p_{10}	Ratio. $\frac{p_{10}}{p}$	Love's formula (11.) p_{11}	Ratio. $\frac{p_{11}}{p}$	Unwin's formulæ (22), (23), (24.) p_{22}, p_{23}, p_{24}	Ratio. $\frac{p_{22}}{p}$ ecc	Belpaire's formula (33.) p_{33}	Ratio. $\frac{p_{33}}{p}$	Remarks.
1	61	18.75	0 25	3.5	15,750	420	406*	0.97	529	1.26	420*	1.00	296	0.70	450	1.07	331*	0.79	146	0.35	Longitudinal lap-joint, Fairbairn's experiment [*a.*]
2	37	9	0.14	4.1	12,150	378	392*	1.04	569	1.51	319*	0.85	248	0.66	427	1.13	378*	1.00	150	0.40	Longitudinal butt joint, Fairbairn's experiment [*b.*]
3	37	9	0.14	4.1	8,421	262	392	1.49	569	2.17	319	1.22	248	0.95	427	1.60	359*	1.37	150	0.57	Longitudinal lap-joint, Fairbairn's experiment [*b.*]
4	21.25	15	0.125	1.41	9,000	150	319	2.13	474	3.16	219	1.46	157	1.04	316	2.11	258	1.72	144	0.96	Longitudinal lap-joint, Fairbairn's experiment [*d.*]
5	17	15.19 × 15.63	0.125	1.1	13,754	220	372	1.69	553	2.51	240*	1.09	235	1.07	368	1.67	301	1.37	175	0.79	Longitudinal lap-joint (steel), Fairbairn's experiment [*e.*]
6	60.5	14.7	0.125	4.1	7,350	125	114*	0.92	170	1 36	124*	0.99	95	0.76	150	1.20	131*	1.05	52	0.41	Longitudinal & transverse joints, Fairbairn's experiment [*c.*]
7	420	42	0.375	10.0	5,433	97	64	0.65	77	0.79	160	1.65	113	1.17	195	2.01	88*	0.91	23	0.24	Longitudinal & transverse joints [*k.*]
8	300	42	0.375	7.1	7,112	127	90	0.71	108	0.85	194	1.53	134	1.05	212	1.67	120*	0.94	32	0.26	Longitudinal & transverse joints [*l.*]
9	360	33.5	0.34	10.7	4,877	99	76	0.76	93	0.94	175	1.76	126	1.27	209	2.12	105*	1.06	27	0.28	Longitudinal & transverse joints [*m.*]
10	276	7.87	0.157	33.8	2,757	110	77	0.70	110	1.00	147	1.36	130	1.19	219	1.99	116*	1.06	26	0.24	Longitudinal & transverse joints [*n.*]
11	71.25	53.75 × 54.5	0.25	1.3	11,445	105	118	1.13	156	1.48	149	1.42	94	0.90	140	1.34	124	1.18	51	0.49	Long'tud'l & transverse j'nts [*f.*]
12	36	54	0.25	0.67	14,105	130.6	239	1.84	311	2.38	225	1.72	133	1.02	227	1.74	175	1.34	101	0.77	Longitudinal butt-joints [*g.*]
13	84	37.25	0.375	2.25	9,933	200	361	1.80	435	2.17	442	2.21	285	1.42	414	2.07	307	1.54	128	0.64	Longitudinal butt-joints (welded) [*h.*]

*Experiment used in deducing formula.

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lindrical furnace flues, so extensively used at the present day in marine boilers. The two flues, marked (*f*) and (*g*), used in the experiments made at the Washington Navy Yard in 1874 (See Section 2 and Nos. 11 and 12 in the table), were made of very thin metal relatively to their diameter. The flue used in the experiment made by the Leeds Forge Company (See Section 2, and No. 13 in the table), while being otherwise an exact representation of a cylindrical furnace flue, was not secured at the end; and there is no doubt that this circumstance altered materially the conditions of the experiment, and was one cause of the low collapsing pressure of this tube.

The influence of deviations from the circular form has never been fully investigated. Fairbairn's experiments proved the weakness of lap-joints; but they comprise only two experiments with elliptical flues, which furnish insufficient data for the construction of a formula as attempted by Belpaire.

There are no records of tests made to determine the quality of the metal used in the construction of any of the experimental tubes.

The behavior of the tubes under increasing pressures during the experiments has been recorded only in a single instance, viz., in the experiment made by the Leeds Forge Company, and then only imperfectly.

While no reliable rules for proportioning and determining the strength of furnace flues can be deduced from the data furnished by the experiments heretofore made, these will be useful for checking the results obtained in future experiments—made with a special view toward determining the resistance of tubes representing the dimensions, construction and conditions of working of furnace flues as they occur in practice. When flues collapse during actual use in boilers the circumstances accompanying collapse and the immediate causes of the failure are seldom known sufficiently well to make such accidents the basis of accurate calculations.

5. Recommendations Regarding Future Experiments on the Resistance of Furnace Flues to Collapse.—Exhaustive experiments on the resistance of furnace flues to collapse should have for their object the determination of the influence which the following elements have on the strength of flues, viz.: 1. The length, diameter and thickness, with the proportions usual in practice. 2. Various modes of construction, *e. g.*, the use of riveted butt-joints and of welded joints for the longitudinal seams, different styles of circumferential joints, and different methods of securing strengthening rings. 3. The kind and quality of the metal of which the flues are made, viz., iron or steel, and especially the ductility and limit of elasticity of the metal. 4. Various elements of weakness common in practice, especially deviations from the circular form, and local weaknesses produced by corrosion and by overheating of the plates.

The usual dimensions of furnace flues of marine boilers may be assumed to vary between the following limits, viz., the length between 30 inches and 84 inches, the diameter between 30 inches and 42 inches, the thickness between $\frac{1}{4}$ inch and $\frac{9}{16}$ inch.

A *first series* of experiments should be made with a special view toward determining the influence of the several dimensions, viz, length, diameter and thickness, on the strength of flues. For this purpose each dimension should be varied at least three times within the above-given limits, under otherwise identical conditions of dimensions, quality of material and mode of construction. All these flues should be made, as nearly as possible, circular; they should be constructed in the manner which is most common in practice, and can be best relied upon to give uniform results; that is to say, riveted butt-joints with internal straps should be used for the longitudinal seams. The same material should be used in this whole series of experiments, and it should be of the kind commonly used in the construction of furnace flues, viz., *Extra Firebox Iron*, or a similar brand, the ductility and limit of elasticity of which have been carefully determined in the testing machine.

A *second series* of experiments should be made with flues, circular in cross section, and identical in every respect with the flues used in the first series of experiments, with the exception of either the mode of construction, or the material, or both; that is to say, some flues

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are to be made of steel or of different brands of plate iron of known quality; others are to be made with welded joints instead of riveted butt-joints at the longitudinal seams; in others, different kinds of circumferential joints connecting the several sections of the flues may be used. At least two experiments should be made with each kind of material and style of joint, but the dimensions of the flues may be varied in each experiment.

A *third series* of experiments should be especially directed to the investigation of the weakening effect of deviations from the circular form. This subject should receive the most careful attention, as an accurate determination of this weakening influence will enable us to proceed intelligently in assigning a co-efficient of safety, to be used in connection with formulæ derived from the first and second series of experiments, and may likewise explain any apparent anomalies in the results of these experiments. Slight deviations from the circular form are unavoidable in furnace flues, and will occur also in the experimental flues of the first and second series; they must be carefully measured and recorded in all cases. In practice, deviation from the circular form may be due to the following causes, viz.: 1. The mode of construction, *e. g.*, when lap-joints are used; in this case the amount will depend on the thickness of the plates. 2. Inaccuracy of workmanship frequently causes a difference of $\frac{1}{2}$ inch or $\frac{3}{4}$ inch in the diameters of flues of ordinary dimensions. 3. Distortion under pressure in consequence of want of homogeneity of the material, or of unequal distribution of strains. No numerical value can be assigned to distortion due to these causes. 4. Distortion due to unequal expansion in consequence of difference of temperatures. The increase of diameter, due to a uniform increase of temperature, such as may occur in practice, is small. The diameter of a 36-inch tube will increase about $\frac{1}{8}$ inch, when the temperature is raised 550 degrees Fahrenheit. Local distortions, due to overheating of plates in places where the accumulation of scale prevents the ready transmission of heat to the water, will vary greatly in amount under different conditions.

To determine the weakening effect of these causes, experiments should be made with flues constructed in the same manner and of the same material as the flues of the first series of experiments. The ratio of thickness to diameter should be likewise in them approximately the same, but their cross section should deviate a known amount from the circular form. In determing this deviation it is not sufficient to measure the differences of diameters, but the actual curves of the cross sections should be accurately measured. To make the results of these experiments comparable, at least two values of sufficient magnitude should be given to these deviations from the circular form in otherwise identical flues.

A *fourth series* may comprise experiments with flues made of old plates corroded to a greater or less degree in an irregular manner, or showing signs of blistering and lamination. In others local weaknesses and unequal distribution of strains may be produced by the application of intense heat. For the latter purpose gas jets, impinging on the crown of the flue may be used, the external cylinder having been filled only partly with water so that the space over the top of the flue is filled with compressed air, which permits the overheating of the plates.

From every plate used in the construction of the experimental flues two specimens should be cut, one lengthwise and one crosswise the fiber, for testing the ductility and the limit of elasticity of the metal in the testing machine. These specimens should have a uniform width, and a length of 8 inches between the shoulders, this being the standard length of test-specimens adopted by the French and English Governments. The elongation of the specimens under increasing strains, after the limit of elasticity has been passed, should likewise be carefully measured and recorded. If possible, these tests should be repeated at high temperatures.

The thickness of each plate must be accurately gauged and its soundness must be carefully tested before it is used in the construction of flues. If the flues fail by local distortion, the bulged plates should be drilled or cut and carefully examined for hidden defects.

The ends of the flues should be securely fastened, as in actual boiler practice.

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The apparatus used in the experiments made at the Washington Navy Yard, in 1874, may serve as a model for futuer experiments. (See Section 2 and Shock "Steam Boilers," p. 113).

The pressure should be applied gradually to the experimental apparatus by means of a force pump. After each increase of 50 pounds, or 25 pounds as the limit of strength is approached, the tube is to be accurately gauged at several places; then the pressure is to be released, and the flue is to be gauged again to determine whether any permanent set has taken place. The element of time deserves particular notice in making these experiments. Especial care is to be taken in every case to maintain each increase of pressure a sufficiently long time to let it produce its full effect. A complete record of all variations in the form of the tubes under pressure, and of all conditions and incidents of the experiments is to be kept.

The form of the tube should be determined before commencing the experiments as well as during its progress, by measurement from a fixed central axis by means of an adjustable radial arm, movable along and around this axis.

While complete series of experiments, as above described, can be undertaken only under the auspices of the Government or other public institution, each single experiment conducted by private parties will be of great value if the above suggestions are followed, and a full record of accurate observations is kept and made public.

ELECTRIC LIGHTING: THE DIVISION AND REGULATION OF THE ELECTRIC CURRENT.*

From Sawyer's "Electric Lighting by Incandescence."

To announce a new work on electric lighting in these days is to excite anew the public interest in a subject which at no time within the last two years has failed to elicit the absorbed attention of all classes. The opinion of an expert in matters relating to the present and probable future condition of this very practical question will, in some measure, satisfy the demand for better knowledge of the problems which the inventors have of late been striving to solve.

The new work of Mr. Sawyer will be found valuable, inasmuch as it describes with exceptional clearness the character of the difficulties to be overcome, and the methods devised by different inventors to meet the requirements of in-door lighting by electricity.

After describing the different types of generators and of incandescent lamps, the author proceeds to the elucidation of the all-important question of the "Division of the Current and Light."

We quote here from chapters IX. and X., the latter being devoted to regulators and switches:

"Division of Current and Light.—Much has been written concerning the loss of light by subdivision of the current, and this has been variously estimated, sometimes as the square and sometimes as the cube of the number of lights among which the current is divided. Upon what data and with what purpose these estimates have been made it is difficult to conceive, for they have no foundation in practical fact.

If to the conducting pipe of a gas system a given volume of illuminating gas is supplied in a given time, and all this gas is consumed in a single burner in order to yield a given light, when we divide the volume of gas thus supplied among two or more burners the total light produced may, indeed, have greatly decreased. We do not, however, supply gas in this manner, but the volume of gas supplied is in direct proportion to the number of burners to be fed.

What is true of gas is equally true of electricity. If a fixed volume of current,

* Electric Lighting by Incandescence and its application to Interior Illumination; by William Edward Sawyer. New York: D. Van Nostrand.

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sufficient for one light, is furnished to a single lamp the maximum effect is produced, and if we divide this fixed volume among two or more lamps the total effect is greatly diminished; but to suppose that such a division is contemplated is to suppose a similar operation in the case of gas, and criticism of statements based upon such a supposition is, simply, waste of time and labor. When we increase the number of lights in circuit, we increase the volume of current in proportion; and the power of the total light is increased in proportion; and the energy expended in producing the light, and therefore its cost, is increased in proportion.

Without at this time entering into any considerations of the fact that the current from a single generator of electricity has repeatedly been divided between from two to two hundred incandescent burners, the operations of the Brush system of voltaic-arc lighting set at rest the question of economical subdivision.

Two machines of the Brush type are selected for comparison, viz., the six-light and the sixteen-light machines, both of which are in practical use throughout the United States—the light of each of the twenty-two lamps being of the same intensity as that of each and every other lamp.

With the six-light machine the total driving power absorbed per minute is 236,940 foot-pounds, or 39,490 foot-pounds per lamp.

With the sixteen-light machine the total driving power absorbed is 618,090 foot-pounds, or 38,630 foot-pounds per lamp.

It is thus clearly shown that for each lamp added to the circuit there is an expenditure of power in proportion to the additional work, the somewhat diminished power per lamp expended in the sixteen-light machine being mainly due to the element of friction, in which the percentage of absorption of power is less in large than in small generators.

As a matter of fact, there is no limit to the divisibility of the electric current. While the possibility and the impossibility of its divisibility become from time to time the subject of controversial discussion, practical subdivision is a daily concomitant of every telegraphic circuit. Even in telephonic transmission the current generated is divided between the transmitter and the receiving instrument, and in some large telegraphic stations the wires radiate from a single generator in several directions, and in the circuit of each of these wires, at towns and cities along their route, there is placed a greater or less number of instruments, each of which is energized from the source common to all of them; and the proportion of current supplied to each instrument is made substantially the same in all cases, by making the resistance of the instruments uniform. The strength of the current thus supplied is, of course, inadequate to the operation of an electric-lighting system, as an ordinary main-line telegraphic battery is inadequate to the operation of even a single voltaic-arc lamp; but if we increase its strength proportionately, and for each telegraphic instrument substitute an electric lamp, we as certainly accomplish subdivision of the electric-light current as subdivision of less powerful currents is accomplished with telegraphic instruments. Indeed, the laws which govern the supply of gas to gas burners and the supply of electricity to electric burners are daily recognized and availed of in the operation of telegraphic circuits.

For instance, in operating a given number of telegraphic instruments in series, we employ a given number of cells of battery. Suppose, now, that we double the number of instruments and the resistance of the circuit; all the instruments, since they receive proportionately less current, become practically inoperative, and we increase the number of cells, and therefore the electro-motive force of the battery, in proportion to the additional work required, which is that of overcoming the added resistance. If, on the other hand, we divide the current from a single generator among two or more lines, each including a number of instruments in series, we require a current of greater quantity; hence we increase the size of the elements of the generator.

In electric lighting there are five methods of dividing the current from a single generator of electricity:

1. The series system. Passing the current seriatim through the lamps, as in the Brush system of lighting.

2. The multiple system. Connecting

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the poles of the generator with two parallel wires, and placing each lamp in a branch running from wire to wire, as in the Edison and Maxim systems.

3. The multiple-series system. Connecting the poles of the generator with two parallel wires, and placing a number of lamps in each branch running from wire to wire, as in the Sawyer-Man system.

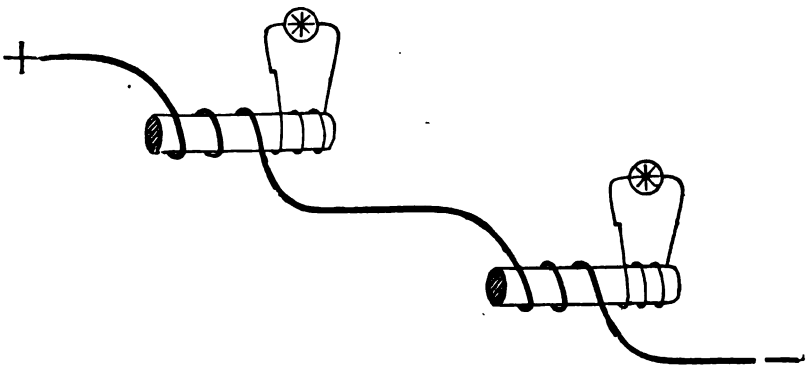

Fig. 66. The Secondary System.

4. The series-multiple system. Connecting one pole of the generator to a wire which, at the point at which light is needed, divides into a number of strands, each containing a lamp or lamps, and which strands again combine together in a single wire, which runs to the next point of division; and so on indefinitely, returning finally to the other pole of the generator; as in the Sawyer system.

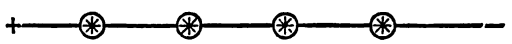

Fig. 67. Lamps in Series.

5. The secondary system. Passing the main current through the primary wire of an induction coil, in the circuit of the secondary coil of which the lamp is placed (Fig. 66).

Alternating or intermittent currents are employed, and, owing to the reactive earth inductions, this principle cannot be applied over any considerable territory. Moreover, it involves loss of power in the heating of the iron core of the induction apparatus, is an indirect application of power, and, in electric as in all other forces, direct application is found to be the most economical. *

How to practically divide the current from a single source among a large number of incandescent lamps has been considered a debatable question. We shall content ourselves with glancing at the results which must follow an extension of the four systems which appear to be suitable, assuming that in each case 1,000 lamps and 10,000 lamps are to be operated upon a single circuit. Where there is a limited number of lamps either the series, the multiple, the multiple-series or the series-multiple systems may be employed with about equal advantage; but where the number of lamps is increased to hundreds or thousands, as must be the case in any general application of electric lighting, considerations novel in character rapidly present themselves.

Taking first the series system (Fig. 67), in which the current traverses the lamps seriatim, and assuming that interruption of the circuit of any lamp will not interrupt the entire circuit, we have with 1,000 lamps a resistance, not includ-

* As recently as 1877-78 several claimants to this method of subdivision have appeared, but the system was patented in England by Harrison in 1857 (Letters Patent 588), under the title, "Improvements in obtaining Light by Electricity;" and it is not quite clear that Harrison was the original inventor. The Harrison patent expired in 1871, unless the Government taxes were unpaid, in which case it must have expired at an earlier date.

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ing the internal resistance of the generator or the external resistance of the main conductor, of 1,000 ohms. With 10,000 lamps the resistance becomes 10,000 ohms.

Can this resistance be overcome by any practicable construction of generator?

The electro-motive force of current necessary to operate an incandescent lamp of one ohm resistance is, as to the lamp, such as will yield a voltaic arc $\frac{1}{8\frac{1}{2}}$ of an inch in length. The electro-motive force necessary to overcome the resistance of 1,000 lamps is, therefore, that which will yield an arc of $31\frac{1}{4}$ inches in length, or with 10,000 lamps an arc 26 feet in length.

Assuming its existence, we need not describe the probable effect of a current of such tension upon the person of any one unfortunate enough to come in contact with the conductor, or the difficulty of insulating the conductor at all; but will simply say that no generator could be constructed around the commutator of which the current generated would not short-circuit. In other words, the current could not be produced exterior to the machine.

With the multiple system (Fig. 68) the conditions are in some respects reversed. The danger of a short circuit occurring in any branch is avoidable, and the electro-motive force of current being low, there would appear to be no difficulty in insulating the main conductors. The questions arising in the operation of this system relate particularly to the generator.

Assuming that the generator is so constructed as to give a useful effect in the external circuit of any percentage of the total current, say 75 per cent., and that the resistance of the lamp used is 200 ohms instead of one ohm (for comparison with a low-resistance lamp would obviously be unfair to a system in which lamps of high resistance only are employed), the internal resistance of the generator would be 66.66 ohms, and the total resistance of the circuit 266.66 ohms. Suppose now that we add another lamp to the circuit of the machine; we reduce the external resistance to 100 ohms, because the current has now two paths to traverse, each of 200 ohms resistance. The total resistance of the external circuit becomes 166.66 ohms, and $\frac{66.66}{166.66}$ of the current is wasted in the machine. Let the number of lamps be ten; then we have an external resistance of 20 ohms, and a total resistance of 86.66 ohms. We thus obtain in the external circuit only $\frac{20}{86.66}$ of the current generated, or about 23 per cent. Extending the calculation to one hundred lamps, thus making the external resistance two ohms, we are able to utilize less than 3 per cent. of the current generated.

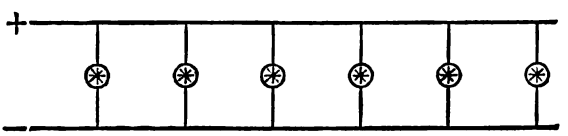

Fig. 68. Multiple Circuit.

In order to be able to operate one hundred lamps with a utilization of 50 per cent. of the whole current, we must, therefore, reduce the internal resistance of the generator to two ohms; with one thousand lamps, its resistance must be reduced to two-tenths of one ohm; and with ten thousand lamps, to two one-hundredths of an ohm. In order that there may be but little loss in the main conductors leading from the generator, they must be of large size, for the resistance of a copper conductor weighing four pounds per foot is substantially four one-hundredths of an ohm per mile; and as there are two mains, the total resistanc) of the conductors, costing, as bare copper at 30 cents per pound, $12,672, is eight one-hundredths of an ohm. With such a conductor, the total resistance of the circuit of 1,000 lamps would be .48 of an ohm, divided as follows: Generator, .2; mains, .08; lamps, .2. There would thus be wasted in the generator $41\frac{2}{3}$ per cent. of the current, and in the

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mains 16⅔ per cent.; utilized as light, 41⅔ per cent. To bring the utilization up to between 49 and 50 per cent., the mains must weigh 32 pounds per foot, and will therefore cost $101,376. The respective resistances will then be: Generator, .2; mains, .01; lamps, .2 of an ohm.

In corresponding ratio the size of one mile mains for 10,000 lamps must be increased, if we desire to approach a realization in light of even 50 per cent. of the current generated, and the internal resistance of the generator must be reduced to two one-hundredths of an ohm. We shall not pause to consider the character of a generator of the required power and of so low an internal resistance, for we have no practical data upon which to base an opinion. The production of a generator of the resistance given, combined with the capacity indicated, is at all events possible. Concerning the requirements of any multiple-circuit generator, however, we are enabled to see that it must be one of multiple induction, the coils of which shall be automatically joined together to form a multiple-internal circuit, which shall both increase the quantity of the current generated and reduce the internal resistance of the generator, in proportion as the number of lamps in the external circuit is increased and the external resistance reduced. In the mechanical construction of such a generator there is a wide field for study and experiment.

Referring now to the multiple-series system (Fig. 69), it is evident that, in operating 1,000 lamps of 200 ohms resistance each, there may be one hundred branches across from main to main, and in each branch ten lamps, which would make the external resistance of the circuit, not including that of the mains, 20 ohms $\left(\frac{10\times200}{100}=20\right)$. With a resistance of five ohms, making the total resistance twenty-six ohms, there is utilizable as light the ten-thirteenth part of the current generated, or about 77 per cent. Applied to lamps of low resistance, as one ohm each, the arrangement would have to be materially changed; for, unless changed, the external resistance of the lamp circuit would be but one-tenth of an ohm $\left(\frac{10\times1}{100}=.1\right)$, and the total resistance of the system 6.1 ohms; whence it follows that we would only be able to utilize in the production of light 1.64 per cent. of the current generated.

Reversing this arrangement and providing 10 branches, each containing 100 lamps, we have a circuit resistance of 10 ohms $\left(\frac{100\times1}{10}=10\right)$; and with a generator resistance of 2.5 ohms, and a resistance in the mains of .25 ohm, mak-

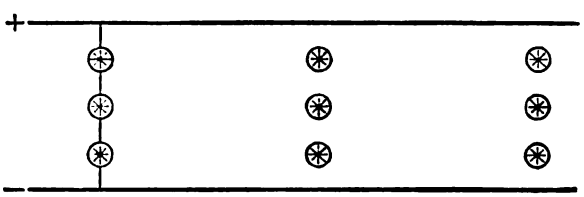

Fig. 69. Multiple-Series Circuit.

ing in the mains of one ohm, and in the gening the total resistance of 12.75 ohms, we are enabled to utilize as light 78 per cent. of the current generated; but we must light substantially the entire hundred lamps in each branch at once and extinguish them all at once, or else we must waste the current which would go to the lamps in equivalent artificial resistances when we extinguish a part of the lamps; for, as the current is to be equally divided among all the branches, a branch must in practice either be entirely cut off from, or its entire resistance interposed in, the circuit.

In the fourth or series-multiple system of subdivision (Fig. 70), as in the multiple-series system, the resistance of the external circuit may be anything desired, and there may be operated in the same circuit very many different combinations of lamps. The main conductor, which is single as in the series system, is cut at the points at which light is

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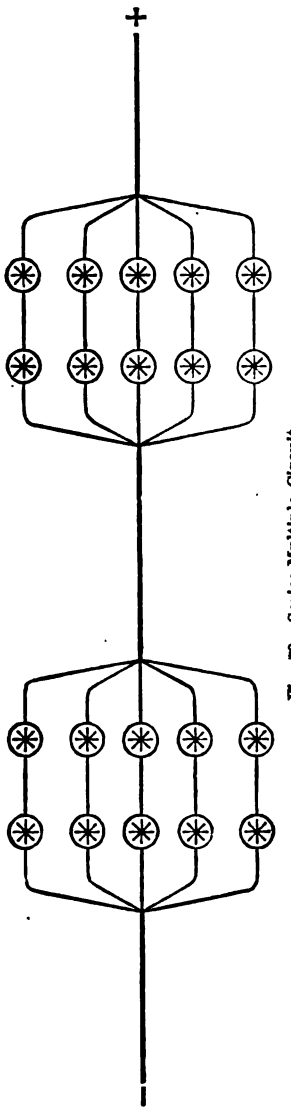

Fig. 70. Series-Multiple Circuit.

desired, and from the two disconnected ends a number of small conductors are run each to a lamp or series of lamps. In the operation of 1,000 lamps by this system there may be, say, one hundred points of divergence, and at each of these points ten lines of wire containing one lamp each. Thus the resistance of the lamp circuit is made 10 ohms $\left(\frac{100+1}{10}=10\right)$ and with a generator resistance of 2.5 ohms, and a resistance in the connecting conductors of .25 ohm, we utilize as light 78 per cent. of the whole current. With 10,000 lamps there may be 500 points of divergence, each containing 20 lamps, by which arrangement the resistance of the lamp circuit becomes 25 ohms $\left(\frac{500+1}{20}=25\right)$; and with a generator resistance of 5 ohms, and a resistance in the connecting conductors of 1 ohm, the proportion of current available for light is 80 per cent. of the total production.

We might continue these calculations indefinitely, but to no further purpose. The flexibility of the system is obviously such as to permit of any regular combination of lamps whatever, and thus to obtain any external resistance whatever; and it will be found to permit equally well of all irregular combinations, so that in one division, where the volume of light required is great, there may be, say, five lamps in multiple, and in the next division, where the volume of light required is ordinary, there may be ten lamps in multiple, each of the latter receiving but one-fourth as much current as each of the former, because the joint resistance of the ten lamps is .1 ohm, while the joint resistance of the five lamps is .2 ohm; and the ten lamps receive but half as much current as the five lamps, while the number of lamps is doubled. The closing-up, short-circuiting, or reducing the resistance of any division acts simply to reduce the resistance of the whole circuit, in the same manner as removing a portion of the lamps in a simple-series system. The relative advantages of the multiple-series and the series-multiple systems can only be determined by the number of lamps operated from a single source and the practical operation of both systems, although there are considerations of simplicity which would seem to favor the series-multiple arrangement of lamps, whose connection with a line of dwellings is illustrated in Fig. 71.

Regulators and Switches.—Although it is matter of common knowledge that a carbon loop or pencil, intensely heated by the passage of the electric current, becomes luminous, it is not generally known what proportion the degree of luminosity bears to the strength of the current. The precise relations of the current supplied and the light produced have never been determined; but results

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which, it is believed, closely approximate the truth were first obtained in August, 1878.

A Sawyer-Man lamp of high resistance (.6 of an ohm) was employed in the tests then made; but it should be borne in mind that, without reference to the length or cross section of the carbon, so long as the current supplied is in proportion to its length and cross section, the percentages observed in one lamp are the percentages of all lamps in which wastage of the carbon by chemical action is obviated. Disintegration at the points of contact when these are imperfect, mechanical disengagement of particles of the carbon, and rupture due to imperfections in the constitution of

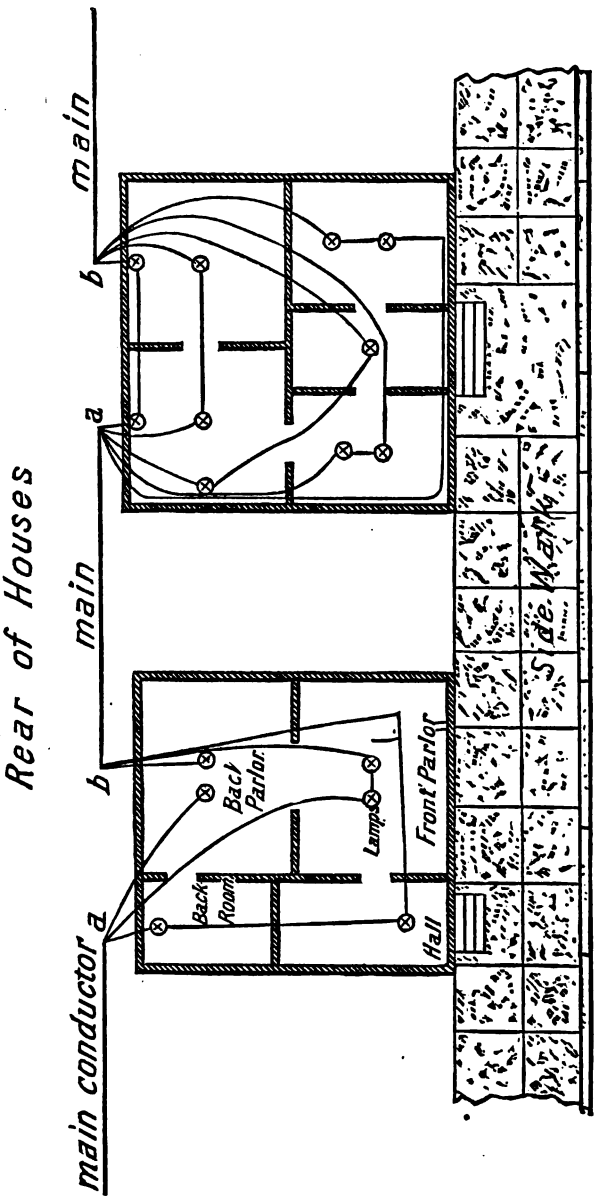

Fig. 71. House-Connections with Main Conductor. a, b, Points of Divergence.

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the carbon are occurrences common to all incandescent lamps.

A dynamo-electric machine wound expressly for the purpose, and driven at an unvarying speed, was used; and as there was abundance of power, and as the speed remained constant under almost any circumstances, it was deemed necessary, in order to obtain a satisfactory result, that the resistance external to the machine should be kept constant. Therefore the internal resistance of the lamp to be experimented upon was measured, and it was found to be as stated. A new form of current regulator, afterwards known as the Sawyer-Man switch (Fig. 72), was employed in the tests.

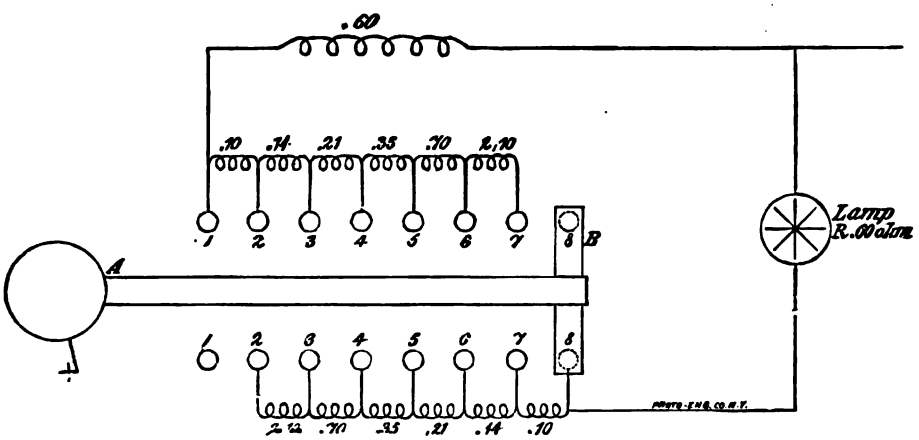

Fig. 72. The Sawyer-Man Switch.

The poles of the generator had connections at the + and − points, A being a sliding-bar, and the cross piece B being a spring contact-piece brought to a bearing upon the two rows of studs 1, 2, 3, 4, 5, 6, 7, 8, accordingly as it is moved backward or forward. Whatever position the cross piece assumes, it will be noted that the resistance of the circuit from the + to the − point is the same. In the position shown, all the current traverses the lamp. With the contact-piece B bearing upon the studs, 7, 7, two paths for the current are afforded, one by way of a resistance of .10 ohm and the lamp outward, making a total resistance of .70 ohm in that circuit, and the other by way of resistance of 2.10, .70, .35, 21, .14, .10, and .60 ohms, outward, the sum total of which series of resistances is 4.2 ohms, thus sending through the lamp six-sevenths of the current, while maintaining the resistance from the + to the − point the same.

It was found that when the volume of current supplied to the lamp was three-sevenths of the whole current, the contact-piece B bearing upon the studs 4, 4, the carbon was brought to a low red heat. With four-sevenths of the current supplied to the lamp, the carbon gave a light of about one candle; five-sevenths of the current, the light, measured by a Sugg photometer, was three candles; with six-sevenths of the current, nine candles; with the whole current, twenty-seven candles. When the contact piece B was bearing upon the studs 1, 1, the whole current passed through the artificial resistance of .60 ohm. The gradations of light by this means being too sudden (from less than one candle light to three candle light, from three to nine, and from nine to twenty-seven candle light), the resistances were subsequently changed so as to admit to the lamp first one-half of the current, then five-eighths, three quarters, seven-eighths, fifteen-sixteenths, thirty-one-thirty seconds, and finally the whole current. With this arrangement the gradations were gradual and pleasing.

The disparity between the volume of current supplied and the intensity of the light obtained is very clearly indicative of the requirements of an incandes-

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cent lamp. Since five-sevenths of the total current for a single lamp produces but three candle-light, while the whole current produces twenty-seven candle-light, or nine times as much, it follows that in order to secure the maximum economy the carbon must be raised to a high temperature. For if we have a supply of current equal only to the maximum requirements of fifty lamps, from which we may obtain a sum total of 1,350 candles, we cannot divide this current among seventy lamps without sustaining enormous loss, as the sum total of light given by the seventy lamps will be but 210 candles, while the expenditure of power will be the same. There is a compensating influence in the case of lamps in series driven by a dynamo-generator, consisting in the increase percentage of current exterior to the generator when the resistance of the external circuit is increased.

To sustain the high temperatures necessary to the economical operation of an incandescent-lighting system the carbon must be hard, dense, and substantial; and in the absence of these qualities is found the explanation for the inefficiency of fine, filamentary carbons, which can never be safely brought above the temperature of a gas flame. Carbon incandescence (that of white light), unlike the incandescence of an iron or platinum conductor, is of two grades and various intensities. In the first the carbon is intensely white, and its form optically broadened and lost in a surrounding haze of light. In the second and more intense incandescence its form stands out sharply defined, and it appears no longer opaque but limpid, seemingly translucent, like the body of the sun. It is to this degree of intensity that economical lighting by incandescence is confined.

The Sawyer-Man switch affords a ready means of dividing the current in any desired manner, while maintaining the resistance of a circuit constant. Thus any number of lamps provided with it may be operated by a single generator, and any portion of them may be regulated to any desired degree of intensity without affecting other lamps in circuit. The objection to its use consists in the fact that when a lamp is extinguished the work of the generator is not lessened, but the entire current that served to operate the lamp is wasted in heating an artifical resistance. It was this consideration that led to the designing of the graduating switch (Fig. 73),

Fig. 73. Small Sawyer Switch.

which is fixed to the wall of a room or in any other convenient place, or attached to the lamp fixture. In this switch, which is illustrated apart in Fig. 74, there is an insulating disc, upon

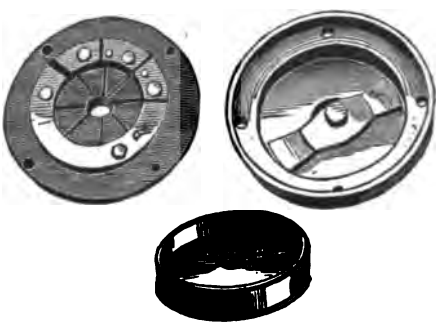

Fig. 74. Switch apart.

which are fixed four brass segments, of a circle. Over this disc is placed the brass enclosing cap, through which passes loosely a slotted iron pin carrying a brass contact bar, which is forced to a bearing upon the brass segments, by means of a steel spring coiled in the head of the cap. Upon the end of the iron pin the finger piece is finally screwed. By turning the finger piece in one direction or the other the light is turned on or off, or regulated to intermediate points of intensity. In Fig. 75 the switch, as attached to the arm of a chandelier or bracket, is illustrated, the circular case at the end of the arm being shown partly in section. The lamp is fixed to the nipple above the switch case, and the insulated conducting wires pass through the hollow arm. The connections of the switch are shown in Fig. 76.

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When both ends of the cross bar A are bearing upon segment 4, the whole current passes through the lamp. When the cross bar bears upon segments 3 and 4, the current divides, a part passing through the lamp and part through the artificial resistance of .50 and .25 ohm. When the cross bar bears upon segments 2 and 4, the current is divided between the lamp and the artificial resistance of .25 ohm. Bearing upon segments 1 and 4, the lamp is short-circuited and practically receives no current. The artificial resistances are preferably made of naked copper wire exposed to the air or embedded in plaster-of-Paris and enclosed in the case (Fig. 75).

By means of this switch it is clear that when a lamp is extinguished its resistance is removed from the circuit, and the current is not wasted in heating an artificial resistance. But in order that changes which take place in its circuit may not add to or lessen the volume of current supplied to other lamps, it is necessary that the changes which occur in its circuit shall in some manner react upon the source of the current; and this brings us to the consideration of

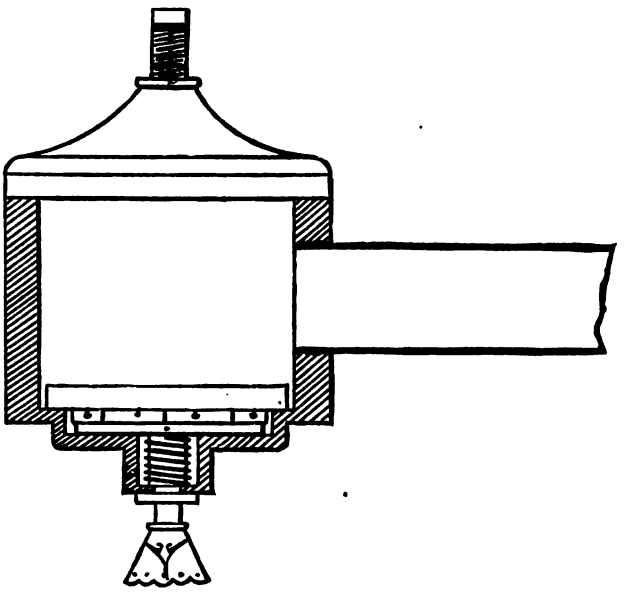

Fig. 75. Switch attached to Bracket.

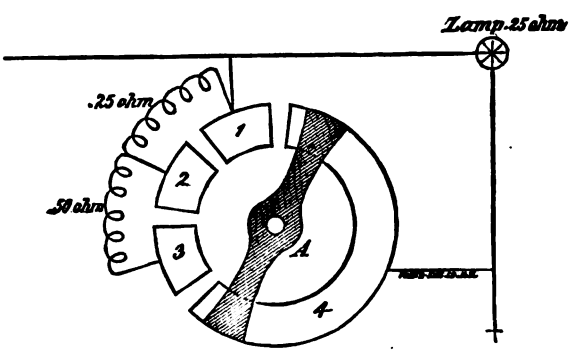

Fig. 76. Switch Connections.

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regulators operating to supply current in proportion to the requirements of a system.

Before taking up this subject, however, a form of switch designed for use upon a circuit of lamps in series, where

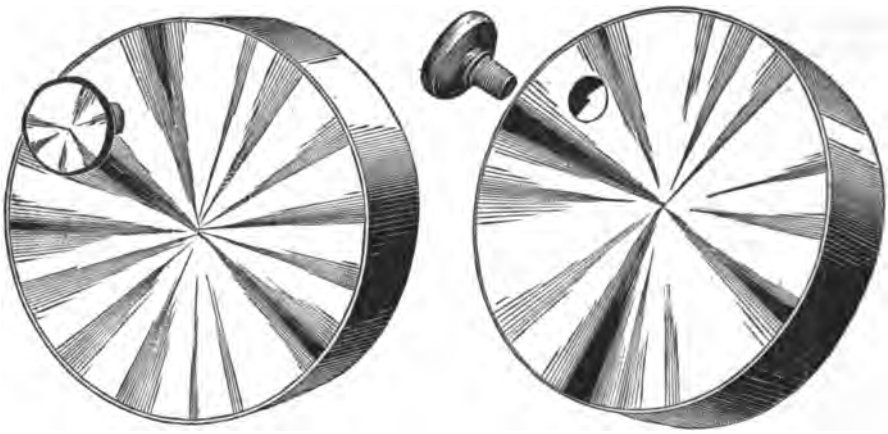

Fig. 77. Electro-Magnetic Switch.

interruption of the circuit at any one lamp would, without it, result in extinguishing all the lamps in circuit, will be described.

In Fig. 77 the switch is shown as fixed to the wall of the room, and also with its cover and finger piece apart. In Fig. 78 the interior mechanism is

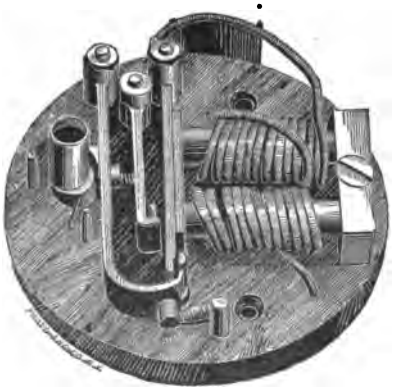

Fig. 78. Mechanism of Switch.

illustrated. In Fig. 79 we have a diagram of the connections.

A is the magnet-lever; B and C are other levers; D is a cam operating to raise and lower lever C, which is pressed downward by coiled spring H. Lever B is pressed upward by insulated spring E. F and G are stop-pins, and I is an artificial resistance.

In the position shown lever A is in contact with stop-pin G. Lever B is in contact with stop-pin F, but not with lever A. Lever C is in contact with cam D, but not with lever A. The current, therefore, passes from the + point through the coils of the magnet to the lamp and outward at the − point, the armature lever being attracted to its contact with stop-pin G and the entire current passing through the lamp. To extinguish the light cam D is moved a little to the right, but not leaving its contact with lever C, when lever C is pressed downward to a contact with lever A. The lamp is thus short-circuited, the current passing from the + point through levers A and C to the cam D and outward at the − point. To give the lamp sufficient current to produce one-half its full light, the cam D is moved further to the right, so as to pass from its contact with lever C. Then lever C, falling further, forces lever A to make connection with lever B, and the current divides, a part flowing from the + point through the coils of the magnet and the lamp outward, and the remainder flowing, by way of levers A and B and resistance I, outward to the − point. With the cam turned to the intermediate point the lamp is extinguished. Turned as far as it will go to the right, one-half of the light is emitted. Turned as far as it will go to the left, the maximum in-

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tensity of light is produced. In the event of an interruption of the lamp circuit the lever A, which, when the circuit is complete, is attracted by the magnet, drops to contact with lever B, and the circuit is re-established by way of resistance I. Lever A can only be drawn towards the magnet when the pressure of spring H is removed by raising lever C from its contact with lever A.

The Edison switch, however, like the switches employed in the Sawyer system, does not interpose current-wasting resistances when no light is required, the supply of electricity being supposed to be regulated at the generator in proportion to the requirements of the circuit.

Many attempts at automatic regulation of the supply of current have been

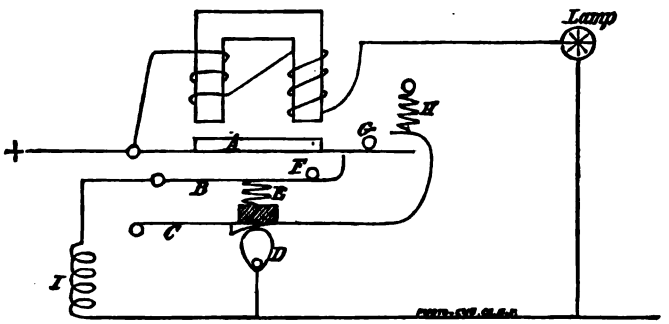

Fig. 79. Electro-Magnetic Switch Connections.

A form of artificial resistance useful in electric lighting is illustrated in Fig. 80, in which a rod of carbon is held in brass connecting clamps upon a soapstone base. A thin piece of platinum, to establish perfect contact, is placed between the end of the carbon and a plate of brass upon which the upper set screw presses. Copper wire for artificial resistances is preferable to iron wire of equal diameter, owing to the greater surface exposed to radiation and convection of heat by the better conductor; and copper ribbon, for the same reason, is preferable to either.

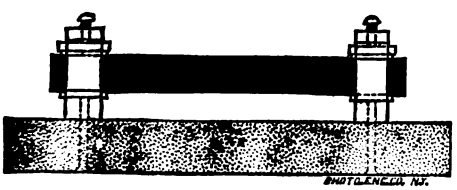

Fig. 80. Carbon Resistance.

In the Edison and Maxim systems of lighting the ordinary make-and-break circuit switch is employed. In respect to simplicity it cannot be improved, but it affords no means of graduating the light, which must either be kept at its full power or entirely extinguished. made both in this country and abroad, the nearest approach to its realization by foreign electricians being the device of Dr. Siemens, who in January, 1879, proposed to place a number of carbon discs in an insulating tube, pass the current through them, and by means of a platinum wire, also in the circuit, to vary the conductivity of the carbon pile by varying the pressure of the discs upon each other. For several reasons, unnecessary to state, this arrangement could have no practical application in an electric-lighting system.

The conditions to be met are not so easily met as might appear from a superficial examination. Let us suppose that there are ten lamps, of one ohm resistance each, arranged in multiple-circuit, and that each lamp receives one-tenth part of the whole current. Suppose, now, that we add a lamp; then each lamp receives but one-eleventh of the former current. We must, therefore, so increase the supply that each of the eleven lamps shall receive as much current as each of the ten lamps received before. To accomplish this increase, there are two very similar forms of regulators, the first of which was patented by Sawyer & Man, June 25, 1878, and the second of which was recently devised by

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Mr. Maxim. The latter is illustrated in Fig. 81. Its operation is as follows: In one of the branches across the two main conductors of a multiple-circuit system is placed the electro-magnet A. A proportion of the current, dependent upon the difference in the resistance of the magnet branch and that of all the multiple-lamp branches, traverses the magnetic coil; and as this proportion varies according to the number of lamps in a circuit, it is obvious that the force with which its armature is attracted varies. When the supply of current is insufficient the armature is released, and by means of a system of gear wheels, operation are such as to cause a rhythmical increase and decrease of the intensity of light from the lamps connected with it, owing to the failure of the armature mechanism to act until the strength of the current has too far exceeded or fallen too far below the point at which it must remain in order to produce no appreciable alteration in the intensity of the light. The interposition of a sensitive relay, operating to open and close the circuit of the magnet A, instead of placing the magnet A in the main circuit, would have operated to maintain the intensity of the light constant.*

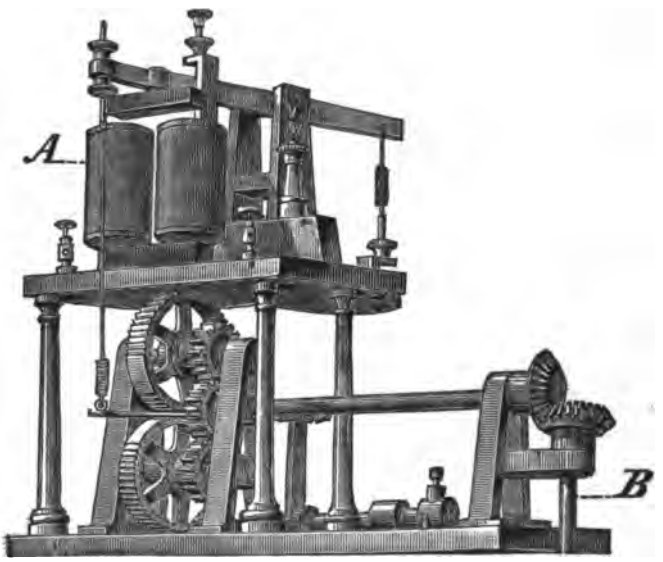

Fig. 81. The Maxim Regulator.

continuously in motion, the shaft B is rotated in one direction, and the commutator brushes of the generator are thereby so set as to supply a greater volume of current. When, on the other hand, the supply of current becomes too great, by reason of the removal of lamps from the circuit, the armature is attracted, and through the system of gear wheels mentioned the shaft B is rotated in the opposite direction, and the commutator brushes are thereby so set as to yield a less volume of current. These are the principles of this regulator, which it is only reasonable to suppose is as yet undeveloped. The considerable changes in current force necessary to its

In the Sawyer system of regulating the supply of current, without regard to the speed of the generator or the electromotive force of the current (Fig. 82), we have first to find the proper relation between the strength of current and the number of lamps to be operated. Let us suppose that there are ten lamps arranged in series, and that the full cur-

* In Letters Patent of the United States, No. 223,659, of January 20, 1880, granted to Professors Thomson and Houston, members of the Franklin Institute of Philadelphia, the principles of this regulator are described, with the following claim:

"As a motor for effecting the adjustment of the commutator-collecting brushes, an electro-magnet, M, traversed by the current, or a portion of the current, of the machine, whose attraction upon its armature, N, moves said commutator-collecting brushes in one direction, motion in the other direction being obtained by the action of a spring."

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rent is exactly sufficient to operate these lamps at their maximum intensity. At any point in the circuit we place an electro-magnet, B, having the sensitiveness of a telegraphic relay. The relation of this magnet towards the regulating apparatus is actually the same as the relation of the telegraphic relay towards the local telegraphic instrument. The armature lever of this magnet is set between two contact points, between which it plays without appreciable motion. Indeed, both points may be in actual contact with the lever, so that the latter shall not move at all; but the local circuit shall be changed by the change in resistance due to the mere difference in pressure of the relay-lever upon the separate contact points. Thus resistance of the lamp circuit is reduced to 1.25 ohms, and the effect of the current upon B is correspondingly increased. Its lever at once actuates the regulating mechanism, which moves lever A to contact with stud 6, thus bringing the resistance of the circuit to its normal point, viz., 2.5 ohms. The same action ensues whenever a lamp is short-circuited, and the reverse action whenever an additional lamp is thrown into the circuit. In practice the resistances D D are greater in number and each of a less value than described, but the sum total of all remains the same. The lever of B in practice is in constant vibration between its contact points, and the lever A is in constant vibration between two contiguous studs or segments of the

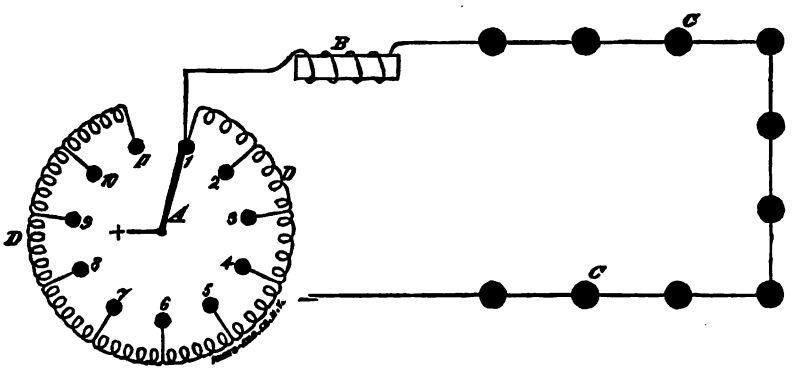

Fig. 82. System of Regulation.

arranged, variations in the strength of the lighting current, sensible only to a galvanometer, may be made to operate the circuit of a local battery, and thus to energize electro-magnetic regulating mechanism.

Let CC be the ten lamps in circuit, and A a rotating contact lever. DD represent a series of ten artificial resistances, the sum total of which is 2.5 ohms. The sum total of the resistance of the ten lamps in circuit is also 2.5 ohms. When all the lamps are in operation, the circuit pases from the + point to the stud No. 1, and thence through relay B and the ten lamps CC to the — point. The resistance of B is for convenience disregarded, as it is but a fraction of the total resistance. Suppose, now, that we extinguish half of the lamps by short-circuiting them. The circle, in addition to its positive movements over a greater or less number of studs.

In the engraving (Fig. 83), from a photograph, is illustrated the Sawyer electro-magnetic regulator. The large gear wheel, whose shaft carries a rotating contact arm, corresponding to lever A of Fig. 82, making connection seriatim with a number of insulated segments of a circle enclosed in an oval-top case, is set in motion by a pinion on the shaft of a small reversing electric engine enclosed in the central round metal case. When there is too great a supply of current, the armature lever of the magnet in the main circuit establishes the local circuit of a commutator which drives the engine in one direction; when there is too little current, the armature lever establishes the circuit of a second commutator which

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drives the engine in the opposite direction. In the first instance resistance is introduced in the main circuit. In the second instance resistance is removed from the circuit.

Imperfections due to the oxidization of contact points in the electric engine, and the occasional failure of the engine to respond to changes in its circuit, led to the abandonment of what was otherwise a successful regulator, and the substitution therefor of hydraulic-cylinder and piston mechanism, constituting the regulator shown in Fig. 84, which is also from a photograph.

The internal arrangements of the regulator are shown in Fig. 85, in which J is a hollow metal base containing the various resistances connected with the 18 pieces F, corresponding to the 10 studs or segments of Fig. 82. B is a cylinder fixed to the base J and open at the top. Closely fitting in cylinder B is the cylinder A, open at the bottom. Supported by a tube passing through the base, and closely fitted in cylinder A, is the piston C. Insulated upon one side of cylinder B is a stationary contact plate E, to which one pole of the generator is attached. Insulated upon the opposite side of the cylinder are the 18 grooved central plates F. Running in the grooves of E and F are two contact arms, G and H, whose pressure upon E and F is regulated by spring I. The current, therefore, passes by way of plate E to arms H and G and a contact plate F outwardly, as shown in the regulator connections, Fig. 82. The ends of the cores of an electro magnet, K, provided

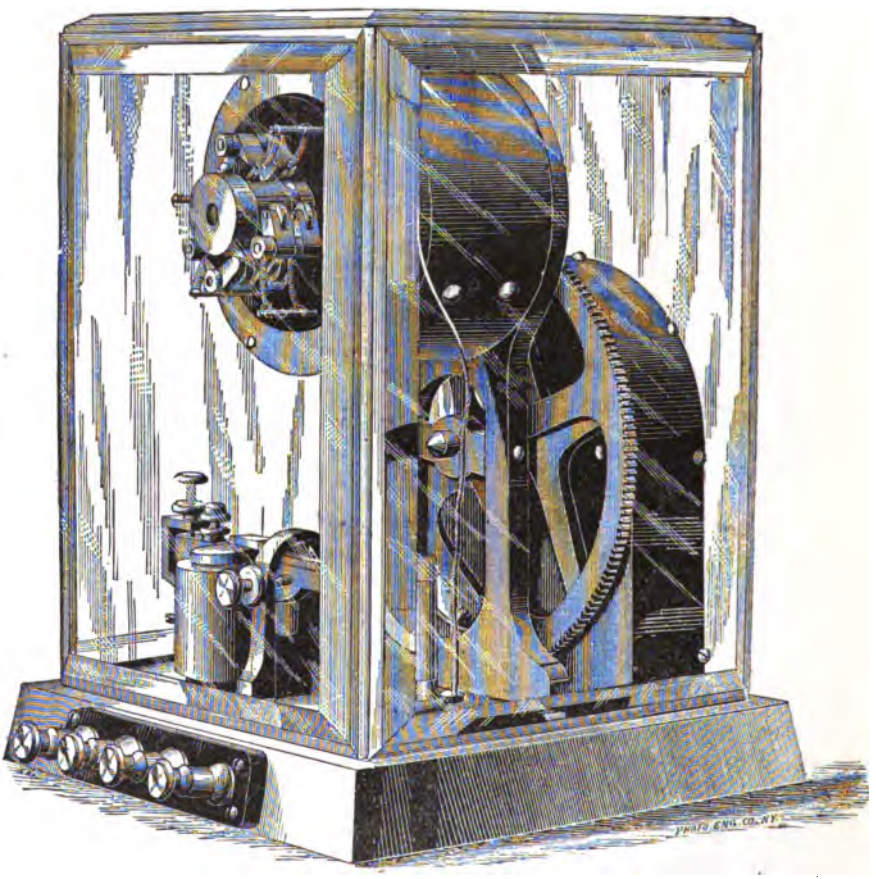

Fig. 83. The Sawyer Electro-Magnetic Regulator.

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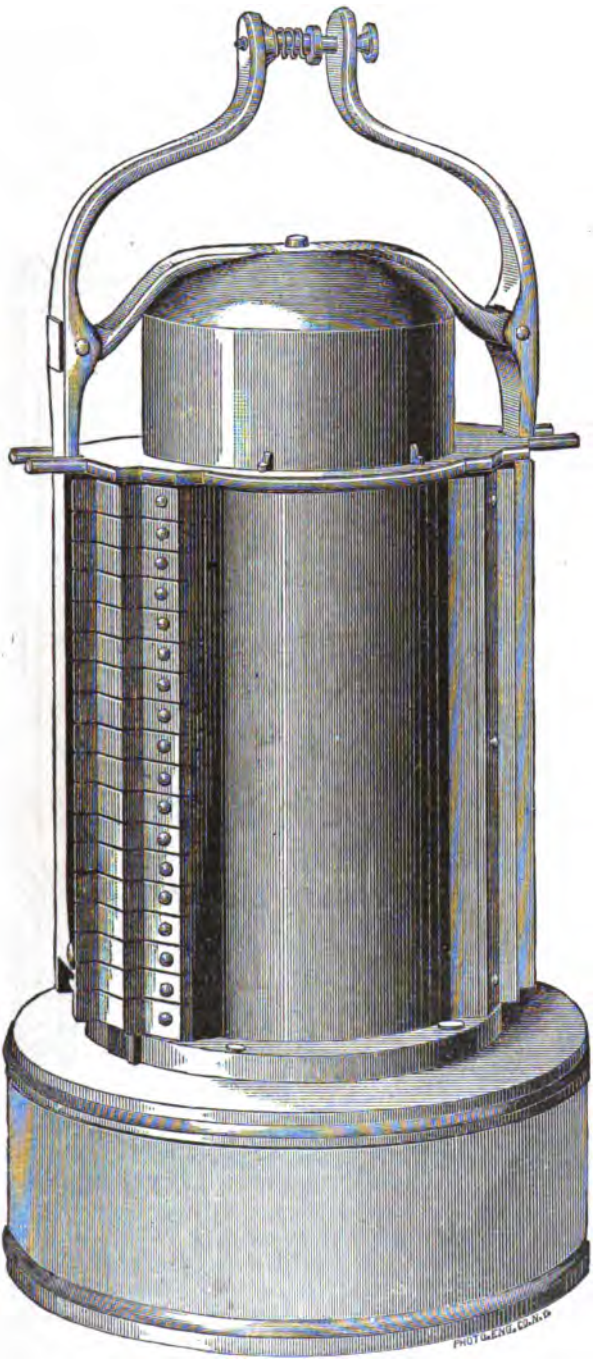

Fig. 84. Hydraulic Regulator.

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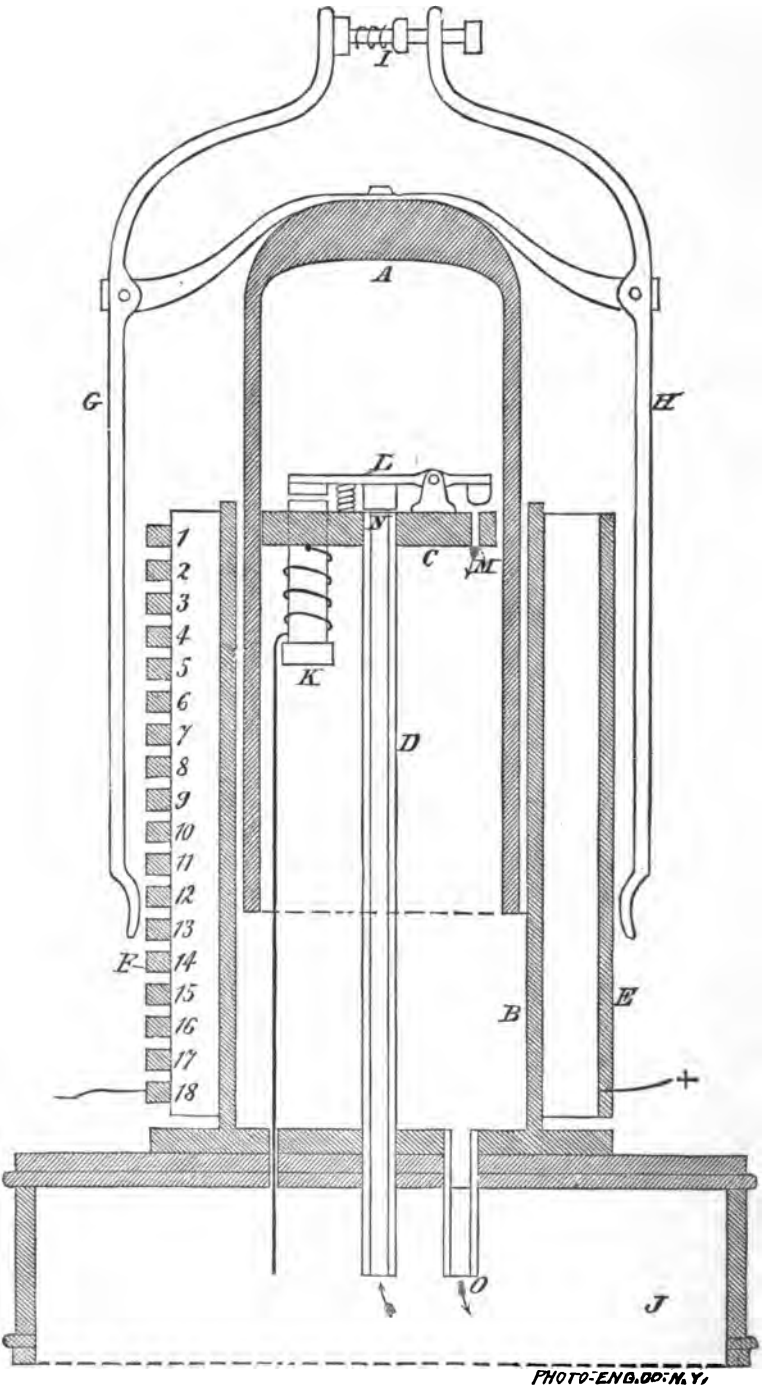

Fig. 85. Hydraulic Regulator Mechanism.

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with an armature lever, L, pass through the piston head, and serve to open and close the valves NM. When the magnet K is not energized, a coiled spring forces the armature away, and valve N is opened to the flow of a stream of water, and valve M is closed against its escape into the lower chamber and outwardly through the exit tube O. Therefore the cylinder A rises. When the magnet is energized, the valve N is closed and the ingress of water stopped, while valve M is opened and the water contained in the upper chamber is allowed to escape. The cylinder A then falls by its own weight as rapidly as the escaping water permits. By a suitable arrangement the waste water is used to cool the various artificial resistances. The local circuit of the magnet K is established by the back contact of the relay lever. The movements of the cylinder A are smooth and the changes rapid. The contacts of G and H with F and E are of a firm and substantial character. With a pressure of 10 pounds of water and a piston area of 10 square inches, the cylinder A is raised above its weight with a force of 50 pounds; and as its weight is 50 pounds, it obviously falls with the same force. With a piston area of 80 square inches and 20 pounds pressure of water, a circuit is operated, with singularly rapid changes in the direction of movement of the cylinder, with an upward force in the cylinder of 1,600 pounds. There is apparently no limit to the powerful effects thus producible by minute changes in the strength of current supplied to a system of lamps. By means of these regulators, the changes in the circuit occasioned by the Sawyer switches for graduating the light are instantly balanced; but the fact remains that as much power is expended in driving the generator when there are a few as when there are many lamps in circuit, and in a general distributing system, where economy is the prime consideration, such regulators, however perfect in their operation, can have no practical application."

Quite as valuable as the above is the author's presentation of the subjects of "General Distribution" and "The Commercial Aspects." But for these topics we must refer the reader to the book itself.

STREET CARRIAGEWAY PAVEMENTS.

By GEORGE FREDERICK DEACON, M. Inst. C. E.

From Proceedings of the Institution of Civil Engineers.

As a branch of civil engineering street paving has never occupied a very high place. It is true that, when once the conditions of its maximum economy and efficiency are ascertained, exceptional skill is not required to put them into practice; but those conditions have rarely received at the hands of engineers the consideration in detail which they demand; and when the very high degree is duly appreciated, in which the welfare of the community is influenced by the method of paving adopted, it must be conceded that the divergent opinions and practice at present extant should at once be formulated and fairly compared. The proceedings of the institution have contained no discussion on the subject for many years. The author therefore proposes to state his practice, and to tabulate its results in a manner which, if generally adopted, will remove much of the present difficulty of making accurate comparisons between the various classes of pavements and the different modes of constructing them.

The present paper will be confined to street carriageways, and will exclude the consideration of such roads as form lines of communication between centers of population, or between scattered rural dwellings and market towns, railway termini, or harbors. The former division of the subject of road making offers abundant matter for consideration in a single paper, and the latter division has been ably dealt with by Mr. W. H. Wheeler, M. Inst. C. E. The details and cost of construction of certain pavements will be given, and their relative ad-

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vantages will then be generally considered.

I. CONSTRUCTION. — CARRIAGEWAYS OF HAMMER-DRESSED STONE, OR SET PAVEMENTS.

Figure of Sets.—Sets when properly secured in position and formed of the hardest stones are so durable, even under the heaviest traffic, that it is not worth while to make them more than from 6 to 7½ inches deep. Two depths are employed in Liverpool: the first for moderate traffic, averaging 6¼ inches; and the second for the heaviest traffic, averaging 7¼ inches. In relation to its other dimensions, a set should be of such depth that when the wheel of a heavy cart passes over one edge of its upper surface it should not tend to tip. The resultant direction of pressure of the load and adjoining sets should, in short, always tend to depress the whole set vertically. Where, as frequently happens, this precaution is neglected, the maintenance of a uniform surface is impossible. This consideration would lead *per se*, for sets of the above-mentioned depth, to a surface of 4 or 5 inches square. Sets of this figure remain comparatively stable, even on bad foundations and with defective joints. There are other influences, however, which lead to a modification of this form. It is desirable that the width of each set measured along the street should be small. If it is large, a horse drawing a heavy load attempting to find a joint slips back, and requires an exceptionally wide joint to pull him up. The wide joint induces increased wear of the upper corners of the sets, and increased noise.

In practice, the author has found that, for all but the softer stones, upon which, even if there were no joints, horses could travel with facility, it is desirable that the widths of the sets should be such that four taken at random, and placed side by side, will not measure more than 14 inches across. As in this measurement the irregular projections of the sets are taken into account, the average surface width is less than 3 inches; and if with this width the surfaces are square, the number of longitudinal joints is so great that it is impossible for the paviors to break joint properly, and at the same time to keep the joints close, without much loss of time in selecting each set as it is placed. Two or more longitudinal joints in nearly the same line, or a single rather wide longitudinal joint, almost invariably initiates a groove.

The square form which, for stability, would otherwise have been the best, has therefore been altered in the author's practice to an oblong of the width above stated, and of a length varying from 5 to 7 inches, which, when the set is fixed in position in the manner about to be described, is not found to be too great in relation to the depth to secure stability.

These conclusions may be summarized as follows:

HARD STONE, IN WHICH JOINTS ARE NECESSARY FOR FOOTHOLD.

	Depth. in. in.	Width. sets. in.	Length. in. in.
Sets for moderate traffic....	6 to 6½	4 to 14	5 to 7
Sets for heaviest traffic....	7 " 7½	4 to 14	5 " 7

SOFTER STONES, IN WHICH JOINTS ARE UNNECESSARY FOR FOOTHOLD.

	Depth. in. in.	Width. sets. in.	Length. in. in.
Sets for light traffic or inclines.....	6 to 6½	3 to 14	5 to 7

Materials of Sets.—Among the igneous, plutonic, and metamorphic rocks are to be found a great variety of stones suitable for paving, of all degrees of hardness, brittleness, and toughness; but the durability under traffic, the tendency to wear round rather than flat and to become slippery, are dependent upon no conditions which can readily be foreseen. The size and distribution of the crystals, the nature and hardness of the constituent minerals, operate in such a manner that two opposite combinations often produce nearly the same result; while rocks of nearly equal hardness frequently behave very differently under traffic. The specific gravity, moreover, appears to afford no assistance in the determination.

The only sedimentary rocks which it is desirable to use for street pavements are some portions of the millstone grits and other more laminated grits of the coal measures, and the use of these should be confined to steep gradients and to streets of little traffic. Specimens of rocks used

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in Liverpool for paving are exhibited, and in the following table (page 240) are stated the localities from which they are obtained, their lithological characters, and their behavior under traffic, so far as is known to the author, when paved as described in this paper.

Mode of Jointing.—Until 1871 the joints of Liverpool set pavements were simply filled with gravel, well worked down with a tool called a cramming iron. In many towns a grouting of hydraulic lime and gravel is brushed into the joints. The first method answers moderately well for streets of light traffic; the second binds the gravel to some extent, but in very few cases do the sets fail to work loose, and the grouting to become disintegrated, even if the vibration of the traffic, which is generally too soon turned upon the pavement, has ever allowed it to set firmly. Joints made according to the first method are always very pervious to water; those made by the second method are less so; but, owing to the fact that the grouting is almost always disintegrated, they are far from impervious.

In pavements of which the foundations are not of concrete, imperviousness is of the utmost importance; for where water can percolate to the substratum, that substratum is softened, and under continuous traffic portions of it work up through the joints, or press the sets upwards in places where the traffic is lighter. In either case hollows are formed. Unless a strong concrete foundation is employed, it is useless to attempt to make the joints impervious with a brittle material such as cement or lime; and so far as the author is aware, the only thoroughly impervious joints under such circumstances have been formed with various asphaltic compositions. For more than thirty years the authorities of many towns in Lancashire and Yorkshire have made the joints of their pavements by first filling them with clean gravel, and then pouring in a boiling asphalt of pitch and creosote oil.

A crucial examination of many classes of pavements satisfied the Author, in 1871, that those jointed with asphalt retained their figures better, and wore out less rapidly, than any others. This method of jointing is often very indifferently performed; and, as it is scarcely known in the South of England, it may be useful to describe in detail the mode which experience has shown to be the best. The sets, which should be dry, are paved as closely as possible, having regard to the maintenance of each course in a straight line, upon whatever foundation may have been prepared for them. If upon a concrete foundation, about $\frac{3}{4}$ inch of sharp sand is allowed to intervene between the pavement and the foundation.

When a considerable area is ready, it is covered with clean, dry, and hard gravel, which has been passed through a $\frac{3}{4}$-inch riddle, and rejected by a $\frac{1}{4}$-inch riddle. When this gravel has been well brushed into the joints, the sets are thoroughly rammed with the old-fashioned two-handled vertical rammer, which the rammerman swings between his legs. The effect of this is to shake the gravel down, and cause it in most places to disappear; more gravel is then added, and the ramming repeated. After a third, if not after the second, gravelling and ramming, each set should be perfectly firm. The vibration of the ramming shakes the pebbles even into the narrowest spaces, where they act as most efficient wedges. The firmness of the pavement even at this stage is generally surprising to those who see it for the first time.

The asphalt is prepared in boilers on wheels. The large-sized boilers for making carriageways contain about 25 cwt. of asphalt, while the small sizes used for repairs contain from 5 to 10 cwt. The coal-tar pitch employed costs in Liverpool about 1s. 6d. per cwt. Care must be taken that it is not too brittle; foremen accustomed to the work can judge of this quality by biting it. Pitch, from which so much of the essential oil has been expelled as to make it brittle, and to raise its melting point too high, will never assume that permanently plastic condition, when boiled with oil, which is necessary to prevent subsequent cracking. The oil employed for softening the pitch is the impure carbolic acid or dead oil from the distillation of coal tar. It is known in the trade as creosote, or creosote oil, but is quite distinct from true creosote. It costs about 2½d. per gallon. About fifty gallons of creosote oil are required for every ton of pitch, but the

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Locality from which sets are obtained.	Description of stone.*	Specific gravity.	Behavior under traffic.
A. Penmaenmawr, Carnarvonshire (old quarry): sets from this quarry have not been laid in Liverpool since 1871.....	Very close-grained. (*Quartz, felspar, hornblende*)	2.75	More durable than any rock known to the author, but becomes very slippery under traffic. Corners apt to wear round by chipping off.
B. Penmaenmawr, sets now used.....	Close-grained. (*Quartz, felspar, hornblende*)	2.82	Very durable; suitable for the heaviest traffic in streets of moderate gradients. Corners apt to wear round by chipping off.
C. Port Nant, Carnarvonshire..	Close-grained. (*Quartz, felspar, hornblende*)	2.70	Very durable; nearly as hard, and not so slippery, as B.
D. Yr Eifl, Llanaelliaiarn, Carnarvonshire.....	Close-grained. (*Quartz, felspar, hornblende*)	2.63	A very tough rock, nearly as hard, and not so slippery, as B. Corners not so apt to wear round. Suitable for the heaviest traffic in streets of moderate gradient.
E. Pistyll, Carnarvonshire.....	Close-grained. (*Quartz, felspar, hornblende*)	2.60	Wears similar to C.
F. Llanbedrog, Carnarvonshire.	Coarse-grained. (*Felspar, quartz, hornblende*)	2.53	Has not been long used in Liverpool. It is not slippery, and is moderately durable.
G. Festiniog, Carnarvonshire...	Rather coarse-grained. (*Felspar, quartz, hornblende*)	2.59	Has not been long used in Liverpool. It is not slippery, and appears to be as nearly as durable as F.
H. Minnford, Portmadoc, Carnarvonshire.....	Close-grained. (*Quartz, felspar, hornblende*)	2.9	Free from slipperiness: harder than J, but in other respects similar.
J. Gimblet, Pwllheli, Carnarvonshire.....	Rather coarse-grained. (*Hornblende, felspar, quartz.*)	2.9	Not so hard as H; free from slipperiness, and wears to a very flat surface.
K. Newry, Ireland.....	Coarse-grained. (*Felspar, quartz, hornblende*)	2.7	These are softer rocks than any of the foregoing; but where the cost is small, they are satisfactory for inclines, or streets of light traffic. They are not slippery.
L. Bessbrook, Ireland.....	Coarse-grained. (*Felspar, quartz, hornblende*)	2.65	
M. Dalbeatie, Scotland.....	Very coarse-grained. (*Quartz, felspar, horndlende*)	2.7	Softer than K and L: not slippery.
N. Bagbie, Creetown, Scotland..	Coarse-grained. (*Quartz, felspar, hornblende*)	2.62	
O. Lancashire.....	Millstone grit.....	2.44	Only suitable for the lightest traffic. May be employed with advantage in streets of very steep gradient.

* The author is indebted to Mr. Isaac Roberts, F.G.S., for the determination of the order of the relative volumes of the constituent minerals, in which order they are placed in the second column of the table.

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exact quantity depends chiefly upon the quality of the pitch. During the process of boiling, the consistency of the asphalt is determined from time to time by cooling small portions in water and kneading it in the fingers.

The hot asphalt is drawn off into iron buckets, each containing rather less than 1 cwt. Each bucket is carried to the prepared pavement on a carrying bar between two men, and the contents ladled out. No attempt is made to run it into the joints without covering the whole surface. The asphalt penetrates the smallest interstices, and for many hours after the joints are apparently full it continues to sink until only a thin coating is left on the surface, with here and there a hole, which is filled from a small ladle. Lastly, the pavement is finished by covering it with small sharp gravel, which, with much of the remaining pitch, is subsequently squeezed into the joints by the traffic.

The cost per square yard in Liverpool, of pavements laid as above described, exclusive of the foundation and of excavation, is as follows :

IMPERVIOUS PAVEMENT WITH ASPHALT JOINTS. AS NOW LAID IN LIVERPOOL.	s.	d.
0.31 ton Stone sets 7¼ inches deep, including cartage, at 28s.	8	8
0.064 ton Gravel for bedding, ¾ inch thick, cartage at 6s. 6d.	0	5
0.015 ton Pitch, cartage at 30s.	0	5.25
0.6 gallon Oil, cartage at 2½d.	0	1.5
0.002 ton Coke, cartage, at 12s.	0	0.25
0.018 ton Shingle, dried and riddled, at 7s.	0	1.5
Labor	0	8.5
	10	6
Add establishment expenses, 8 per cent.	0	10
Total per square yard.	11	4
Similar pavement with sets 6¼ inches deep per square yard	10	4

Pervious pavements with ordinary gravel joints as formerly laid in Liverpool (present prices per square yard):

	s.	d.
0.31 ton stone sets, 7¼ inches deep, including cartage, at 28s.	8	8
0.096 ton gravel for bedding, 1 inch thick, including cartage at 6s. 6d.	0	7.5
0.02 ton gravel for joints, 1 inch thick including cartage, at 6s.	0	1.5
Labor	0	5
	9	10
Add establishment expenses, 8 per cent.	0	9
Total per square yard	10	7
Similar pavements with sets 6¼ inches deep per square yard	9	6

FOUNDATION.

It has already been stated that in 1871 the author gave the preference to asphalt-jointed pavements. Prior to that time they had never been employed in Liverpool; and as the Liverpool traffic was probably heavier than that of any other town, it became necessary to consider whether, in addition to the change in the method of jointing, any alteration should be made in the foundations of the carriageways.

In the oldest Liverpool streets the sets had simply been paved upon an old macadamized surface, but in those more recently constructed, it had been usual to form foundations after the manner adopted by Telford for highways, of which the wearing material was broken stone. Those foundations consisted of rough stones, 10 or 12 inches long, set on end by hand to the proper curvature of the road. The tops of any projecting stones were broken off, and the hollows filled in with smaller stones and rolled. The traffic was then allowed to pass for several weeks before the pavement was laid.

	s.	d.
Present cost per yard of hand-pitched foundation, as formerly adopted in Liverpool	1	5
Add for establishment expenses, 8 per cent.	0	1.86
Total per square yard	1	6.86

Apart from all other considerations, this method of forming the foundation was obviously undesirable, where it was necessary to reconstruct the pavements of existing streets, on account of the long time occupied in consolidation.

In Manchester, where the pavements were, on the whole, the most perfect the author had seen in any of the towns examined, the sets were simply laid upon a well-consolidated bed covered with cinders, and the impervious joints were trusted to prevent the unequal sinking so generally caused by water soaking into the foundations; but where heavy traffic constantly passed over the same lines, the sets did undoubtedly sink beneath those lines. The author decided, therefore, that, for the heavier traffic at least, it was desirable to employ con-

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crete foundations. Subsequently asphalt-jointed pavements were tried, both with and without concrete foundations, with so marked an advantage in favor of the concrete that it has since been used in all except the quietest streets, and within the last six years about 200,000 superficial yards have been laid. The methods adopted have varied slightly from time to time, but experience has led for some years past to the following practice: The concrete employed is either Portland cement or bituminous concrete. Before reconstructing a carriageway for heavy traffic, parts of the existing foundation are exposed in many different places. If, as often happens, no part of this foundation is worth retaining, the ground is excavated to the proper depth for Portland cement concrete. If, as sometimes happens, either an old macadamized road, or an old hand-pitched foundation, is met with at a sufficient depth below the base of the proposed pavement, Portland cement concrete is still employed. If, on the other hand, the macadamized surface or the hand-pitching reaches in places close up to the pavement, so that only a very thin stratum of concrete can be used without removing it, bituminous concrete, incapable of cracking, is used in preference to the comparatively brittle Portland cement concrete.

Portland Cement Concrete Foundations.—Where, as in the case of a carriageway foundation, a comparatively thin stratum of concrete is required, it is especially necessary that that stratum should be uniform in strength, or homogeneous, if the term can be properly applied to such a mixture. The most perfect concrete which the author has produced is made as follows:

The ground on which the foundation is to be laid is first well watered; upon it is then scattered a layer of wet broken stone like coarse macadam; upon this layer is spread with the spade a thin stratum of cement mortar, and upon the mortar a further layer of wet broken stones. The upper layer of broken stones is then beaten into the lower layer with beaters like large spades, with straight handles 4 feet 4½ inches long and flat beaters of sheet iron about 12 inches square and ¼ inch thick. Another stratum of mortar, followed by a third of stone, is then laid, and the beating process continued; and so on, until the required thickness is attained, when the surface is first beaten and then finished by rubbing with the beaters to the proper curvature of the carriageway. The surface is thus made as smooth and uniform as a plastered wall. By this method a complete but thin coating of mortar is left round every stone, and a maximum of strength is attained with a minimum of cement. When cut through, no sign of lamination is found. The mortar is composed of six parts by measure of gravel and one of Portland cement. The broken stones, measured separately, represent about eight parts, but when the whole is mixed and beaten together, the proportion of stones and gravel to set cement, is as 11 to 1. This, however, includes the upper layer, in which there is more than the average proportion of mortar.

No cement is allowed to be used, the tensile strength of which is less than 800 lbs. on a section of 2¼ square inches, or which sets in less than three hours so firmly as to take no impression from a Vicat's needle, having an area of $\frac{1}{400}$th part of a square inch and a weight of 2½ lbs., or of which more than 10 per cent. is rejected by a 50-gauge sieve. Though seldom laid more than 6 inches in thickness, this concrete is so strong that when, for the purpose of laying new service pipes, or of reaching old ones, it has to be removed, it is simply cut with a saw-pick, just as slabs of stone are quarried, in pieces about three feet square. When the excavation has been refilled and rammed, these blocks are relaid, cemented to the old concrete, and paved upon at once. On the following day the traffic is allowed to pass over them, and no subsequnnt sinking has ever been known to take place—a striking contrast to the old system, in which the paving over trenches in streets of considerable traffic was generally relaid three times, and sometimes oftener.

The author desires to lay great stress upon the homogeneity and strength of the concrete, which renders it possible to saw it out, and upon the smoothness and exact form of the surface, which not only insures uniformity of the subsequent paving, but guides the workmen in replacing cut-out blocks.

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Experience has shown that concrete, made in the manner described, should not be paved upon for at least eight days after being placed *in situ*. Eight days is a serious addition to the time during which part of a street must be closed for pavement, but in order to obtain the best result the inconvenience must be endured; moreover no real advantage is gained by paving one-half at a time, and leaving less than one-half open to traffic. It is impossible under such circumstances to do the work so well; it is impossible to do it so quickly; and the blocks which take place in the traffic create, in the author's opinion, more inconvenience on the whole than if all the traffic sought from the first a different route. The most important thoroughfares in the greatest forwarding town in the world have been repaved with Portland cement concrete foundations within the last six years. The idea of closing them entirely was at first not contemplated, and when it was adopted many complaints were naturally made. Those who know the central three miles of Liverpool-dock streets can well understand this; but it will be shown later on that the loss was rapidly recouped; and since the first few thousand yards of the new pavements were opened, warehouse owners and carriers have alike submitted, without complaint, to the temporary loss, for which they obtain so great a return.

Owing to the mode in which the broken stone is added, the quantity of concrete to be mixed on the boards is less by about 50 per cent. than under the ordinary system. Hitherto the work has been performed by hand, as follows: Each man stands before a board 4 feet square with three sides 8 inches high. The boards are placed in the segment of a circle, touching, or nearly touching, each other, with their open edges towards the center. Behind and between every pair of boards is a frame of galvanized iron supporting a galvanized iron cistern of about 3 cubic feet capacity. From each cistern project two pipes, fitted with roses and taps, one over each board. Hinged to the back of each board is a box, having a capacity of 1½ cubic feet. This box has a strong handle, by which its contents may be readily tipped on to the board. Behind the boards are tipped the gravel and the cement. Suppose the boards to be lettered from A to G. Box A is filled from behind by the gravel man, then B, then C, and so on to G. Mixer A pulls over box A with his spade, and spreads out the gravel, over which the cement boy, who follows the gravel man from A to G, scatters the cement from a hemispherical vessel, containing ½ cubic foot. Mixer A then turns over his gravel and cement, until thoroughly incorporated. He next turns the tap on to a bare part of the board, and shovels over the mixture, scattering it among the spray. An experienced man will scatter the mixture at such a rate that when all turned over it will have exactly the required dampness. The tap is then turned off, and very little more labor is necessary to make the mixture perfectly uniform. By this time a cart or a barrow has arrived from board G. Having discharged the contents of his board, mixer A finds that the gravel man from G has already filled his box, which he pulls over as before, and the whole cycle of operations is repeated. It is obvious that close supervision of such a system is very easy.

One of the most important results effected by the process is perfect mixing with very little water. The concrete is only so far wetted that when squeezed forcibly in the hands a slight dampness appears on the surface. So small is the quantity of water used, that many persons accustomed to concrete mixing have remarked that the mortar will not set properly without more water. Concrete formed with mortar of this consistency can be beaten into a much more compact mass than when a larger proportion of water is used; it is much stronger, and can be formed to a more accurate figure at the surface.

In the earlier trials of this work in Liverpool, the concrete mixing was performed in the street. A carriageway, running, for example, north and south, having been closed, the excavation, commenced at the north end, was proceeded with, at first by carting both northwards and southwards. When a sufficient opening was made the concreting was commenced at the northern end, the mixers being placed south of the concrete, and the materials for concrete south of the mixers. As the concreting progressed, the mixers were moved southwards. It

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was found to be impossible to mix so much concrete within the limits of the carriageway as could be laid *in situ* in the same time, and the work was much impeded by the limited space.

In order to ascertain whether any mode of mixing at a short distance from the site could be devised which would not diminish the strength of the concrete, owing to subsequent disturbance in laying, the author tested carefully-prepared samples of concrete, some moulded immediately after mixing, and others moulded, and thus disturbed, at different periods after mixing. In a modified degree the results had been anticipated; but the incorrectness of the prevalent opinion as to the effect of remixing was shown to be much greater than was expected, so far at least as concrete made with good slow-setting Portland cement was concerned.

A summary of the results of four hundred and eighteen experiments, both in compression and tension, which determine this question, are given in the following table (page 245).

Since the time when the first set of these experiments was made, concrete mixing in the street for which the concrete is destined has been abandoned, and any convenient yard or other place has been used, from which the concrete may be deposited within a moderate time after mixing. In the author's opinion, the change has not diminished the strength of the concrete.

It is well known that fresh Portland cement is unfit for use, on account of the large quantity of uncombined lime it contains. If moulded in this condition the lime slakes while the cement is setting, and often breaks it up completely. To avoid this the cement must be thoroughly purged, that is, exposed to the atmosphere for a considerable time. By this means the lime is slaked to a sufficient extent to prevent any failure of the work from subsequent slaking. This action diminishes as the purging becomes more complete; but even in the best Portland cement after exposure to the air for an indefinite time there is rarely a diminution, though there is sometimes an increase of strength if allowed to stand fifteen or twenty minutes between the process of mixing and placing *in situ*. It is difficult to ascribe any cause for this except on the hypothesis that even in the best purged cement there remain minute points of compression, scattered throughout the mass and produced by minute particles of lime, which are slaked on the application of water. Whether or not this be the true explanation, the facts are indisputable, and have an important bearing upon many works in concrete.

The cost per superficial yard of Portland cement concrete foundations in Liverpool, six inches deep, constructed in the manner above described, is as follows:

	s.	d.
0.132 ton Broken stones, including cartage, at 6s.	0	9.5
0.174 ton River Dee Gravel, including cartage, at 5s. 6d.	0	11.5
0.024 ton Portland cement, including cartage, at 52s.	1	3
Labor, mixing concrete.	0	3.25
Labor, laying *in situ*, beating and shaping.	0	2.75
	3	6
Add for establishment expenses, 8 per cent.	0	3
Total per square yard...	3	9

Bituminous Concrete Foundations.—The positions in which bituminous is preferred to cement concrete, have already been described. It is constructed in Liverpool as follows: On the hard but often irregular bed of the old foundation, previously well brushed, is thrown the required thickness of broken stone of the size of rough macadam. This is well leveled and rolled to the proper form, and over it is poured precisely the same asphaltic composition as that above described for making the joints of sets. The asphalt sinks to the bottom, and fills the smallest crevices between the stones. On the surface, while the asphalt is still warm, is laid a thin stratum of small broken stone, which is thoroughly rolled into the asphalt, and fills up the upper spaces between the larger stones. As in the process of rolling the soft asphalt rises between the smaller stones, still smaller riddlings are scattered over it, until a perfectly true and uniform surface is obtained. In a few hours this

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AVERAGES OF 418 TESTS OF PORTLAND CEMENT AND PORTLAND CEMENT CONCRETE, PLACED IN SITU AT VARIOUS INTERVALS OF TIME AFTER MIXING.

Number of Minutes between Mixing and Moulding....	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
Means of crushing strengths of 24 blocks, 5 parts river gravel, 1 part cement; 1 cube foot each; tested 26 and 28 days after moulding. Tons per square foot.....	45.55	..	..	..	49.00	..	>50.00*	..	48.58	..	47.07	..	45.15												
Ditto, ditto; 24 and 28 days after moulding. Tons per square foot.....	49.57	..	..	..	..	..	>50.00*	..	..	>50.00*	..	..	47.56	..	46.55	..		..	43.55						
Means of tensile strengths of 240 2¼-square-inch sections of pure cement, and Oporto gravel and cement varying from 1 to 1 to 4 to 1; pure cement tested 7 days, concrete 14 days, after moulding. Lbs. per 2¼-square-inches.....	..	602	579	571	604	593	599	594	609	523	498	567	507												
Means of tensile strengths of 144 2¼-square-inch sections of pure cement, and Oporto gravel and cement varying from 1 to 1 to 5 to 1; pure cement tested 7 days, concrete 14 days, after moulding. Lbs. per 2¼-square-inches.....	..	..	593	..	590	..	581	..	578	..	580	..	588	..	581	..	562	..	544	..	566	..	560	..	524

*50 tons was the greatest compression capable of being applied by the machine employed.

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surface will bear any amount of ramming without distortion.

The cost per square yard of bituminous concrete foundations in Liverpool, 6 inches deep, is as follows :

	s.	d.
0.153 ton Broken stones, including cartage, at 6s.	0	11
0.041 ton Pitch, including cartage, at 30s.	1	3
1.2 gallon Oil, including cartage, at 2½d.	0	3
0.007 ton Coke, including cartage, at 12s.	0	1
Labor	0	9
	3	3
Add for establishment expenses, 8 per cent.	0	3
Total per square yard...	3	6

CARRIAGEWAYS OF BITUMINOUS CONCRETE, OR ASPHALT MACADAM.

A pavement may be constructed precisely in the same manner as the bituminous concrete foundations above described. It is absolutely impervious to moisture, and in first cost less expensive, though by no means so durable as a stone pavement, or as a rock-asphalt pavement ; but, nevertheless, it is sufficiently durable for the numerous back streets of a great town, in which facility of cleansing is of primary importance.

In constructing such pavements it is desirable that the upper layer of large stones should be of smaller size than is necessary for concrete, and that they should not be harder than limestone. The still smaller stones and riddlings should be similarly limited in hardness. The object of this proviso is that the asphalt between the stones may not wear down much more rapidly than the stones, and thus leave in time an uneven surface. The proper consistency of the asphalt is of even more importance than when it is simply used for joints. About 23,000 square yards have been laid in Liverpool, and on sanitary grounds the system will probably be extended annually over large numbers of back streets.

The cost per superficial yard of bituminous concrete pavements 6 inches deep, as constructed in Liverpool, is as follows :

	s.	d.
0.144 ton Broken stone and lime-stone chippings, including cartage, at 7s. 6d.	1	1
0.041 ton Pitch, including cartage, at 30s.	1	3
1.2 gallon Oil, including cartage, at 2½d.	0	3
0.007 ton Coke including cartage, at 12d.	0	1
Labor	0	10
	3	6
Add for establishment expenses, 8 per cent.	0	3
Total per square yard.	3	9

Bituminous concrete is usually prepared in other places by pouring coal tar over broken stones of the size of macadam and previously heated. The stones are then laid, and thoroughly rolled to the contour of the finished surface ; after which about an inch of similarly prepared chippings, by preference limestone, is spread upon them and thoroughly rolled.

The author tried this method in Liverpool, but subsequently obtained greater success by the first method described. In some Lancashire towns where the second method is employed, the surfaces appear generally to become disintegrated more readily than those in Liverpool. Recently, however, he has examined some street carriageways laid in Derby by Mr. Clement Dunscombe, according to the second method, and they are among the best artificial asphalt pavements he has seen. As creosote oil cannot readily be obtained in all towns, and as tar can be obtained wherever gas works exist, a knowledge of the details of Mr. Dunscombe's practice and experience would be of great service to the surveyors of provincial towns, even if it does not supersede the first method where creosote oil is cheap.

WOOD PAVEMENTS.

In Great Howard Street, Liverpool, where the traffic exceeds 3,300,000 tons annually, or 216,000 tons per yard width of carriageway, one of the most important hospitals in Liverpool is situated. Near all hospitals it is of course desirable to reduce the noise to a minimum. At first this was done by the use of macadam in the middle half of the carriageway ; but the difficulty of main-

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taining it became so great, that in 1871 a set pavement was laid. In 1872 the author recommended the substitution of timber. The northern half of the work, about 700 square yards, was accordingly paved in 1873 by the Improved Wood Pavement Company. The site having been excavated and leveled, boards of Baltic pine, 1¼ inch thick, were laid diagonally upon 3 inches of sand, and upon these a second layer of similar boards was spiked. The blocks of wood were of Baltic pine, 6 inches deep, 7 inches and 8 inches long, and 3 inches wide. The ends were placed in contact, and a space of ¾ inch was maintained between each row by a narrow strip of wood nailed to the planking. This space was subsequently caulked with gravel and a bituminous composition. The whole surface was finished with a coating of asphalt and gravel. This work was subject to very frequent repair and was entirely relaid after four years use. The defects were due chiefly to the absence of a proper foundation, for though the blocks had worn down from 2 to 2½ inches during the four years, they would, if properly held in position, have lasted some time longer. The author declined to recommend the further trial of wood in this place unless laid upon a good bed of concrete. Accordingly, in 1877, a pavement, the surface of which was similar to that employed in the first instance, was laid upon a bed of bituminous concrete, constructed as already described, and underlying the plank foundation.

The southern half of the work, about 700 square yards, was also laid in 1873, by different contractors, on a material which was dignified with the name of concrete. The blocks were of Baltic pine, grouted with Portland cement mortar, a material quite unsuited for use in combination with wood. Notwithstanding the consolidating action to which for years the ground had been subjected, the lines of heaviest traffic soon showed signs of sinking, while the adjoining blocks were pressed upwards; and after ten months' use, the pavement became dangerous, and was entirely relaid on the same system, at the contractors' risk. This pavement had to be removed in twelve months, when a wood pavement similar to that originally laid on the northern half was substituted. The pavement shows very plainly the want of a concrete foundation.

In 1874 the pavement of Bold Street, 4,250 superficial yards, was laid by the Improved Wood Pavement Company, in a manner precisely similar to the northern half of the Great Howard Street work. It is a shop street, with a traffic consisting chiefly of carriages, amounting to about 94,000 tons per annum per yard in width; but even here the want of a concrete foundation soon became manifest, though on the whole the pavement has worn, with moderate uniformity, to the extent of about ⅛ of an inch in four years.

When it became desirable to continue wood pavement along the upper part of Church Street, the author accordingly recommended a bituminous concrete foundation, 3½ inches thick, which was laid under his direction in 1878. Upon this the Henson Street Paving Company laid their pavement, which consisted simply of pine blocks from Soroka, 3 inches by 6 inches by 9 inches long, separated only by a single thickness of tarred felt, a layer of which was also placed between the foundation and the blocks. A transverse V groove, 1 inch wide, was cut by the contractors in a row of blocks at every 12 inches, ostensibly with the object of preventing horses from slipping. Owing, no doubt, to the nature of the foundation, this pavement has retained its original form better than any wood pavement the author has seen.

The author has not hitherto required the surface blocks of wood pavement to be creosoted, but they have always been selected with the greatest care. The foundation boards when used have been creosoted with not less than 10 lbs. per cubic foot.

In order to maintain a wood pavement in good condition, it is necessary to scatter fine sharp siliceous gravel over it from time to time. This operation adds considerably to the cost of maintenance, but if properly done, it prevents slipperiness; and if not overdone, the little angular pieces become so firmly embedded in the fibres of the wood that they are prevented from rolling, and are gradually worn away on one side only.

The first costs of the wood pavements

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most recently laid in Liverpool have been as follows:

COST OF WOOD PAVEMENTS PER SUPERFICIAL YARD.

	s.	d.
Improved wood pavements, as laid in Great Howard Street, in 1877, including double plank foundation.	16	0
Improved wood pavement, as laid in Bold Street, including double plank foundation	15	3
Henson's wood pavement, as laid in Church Street, including bituminous concrete foundation 3½ inches deep	15	10

It is scarcely just to wood pavement, however, to compare these figures with those previously given for other classes of pavement. In the case of the wood pavements, the work was executed by London companies; in the case of the other pavements, by the workmen of the Corporation; and the 8 per cent. allowed in the latter case for establishment expenses, would inadequately represent the additional cost necessarily involved in the contract work.

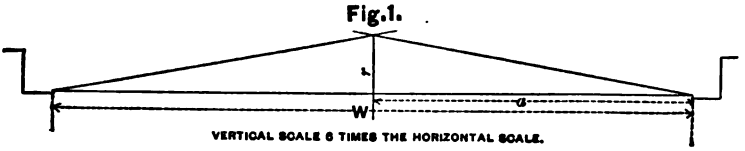
With Liverpool prices at the present time, the actual cost per square yard of wood pavement, with blocks 6 inches deep and bituminous concrete foundation, would be as follows:

	s.	d.
Bituminous concrete	2	0
Creosoted Baltic pine blocks, pitch grouting, and gravel, including labor	12	0
	14	0
Add for establishment expenses, 8 per cent.	1	1½
Total	15	1½

MACADAMISED CARRIAGEWAYS.

There are no thoroughfares near the center of Liverpool, and but few in the outskirts, which are still paved with macadam. The cost of maintaining macadamised carriageways where the traffic is great is so much in excess of the cost of maintaining set pavements; the dirt in wet weather, and the dust in dry weather, are so objectionable; and the quantity of detritus washed from them into the sewers is so large, that for many years they have been abandoned except for a few leading carriage thoroughfares to the outskirts. The proper construction of the substratum of macadamised roads is well known, but not always followed. Much difference of opinion exists, however, as to the best mode of finishing or blinding the surface. The author has tried many methods. Under a 15-ton steam roller, preceded by a watering cart, 1,200 yards of trap-rock macadam, without blinding, can only be moderately consolidated by twenty-seven hours' continuous rolling. If blinded with hard rock chippings from a stone breaker the same area may be moderately consolidated by the same roller in eighteen hours. If blinded with siliceous gravel from ⅜ inch to the size of a pin's head, mixed with about one-fourth part of macadam sweepings obtained in wet weather, the area may be thoroughly consolidated in nine hours. Macadam laid according to the last method wears better than that laid by the second, and that laid by the second much better than that laid by the first.

Fig. 1.



VERTICAL SCALE 6 TIMES THE HORIZONTAL SCALE.

CONTOUR OF CROSS-SECTION.

For the purposes of traffic, and traffic alone, the best form of cross section for a carriageway would be a level line, as any cross-fall produces friction, additional traction, and wear and tear of horse and vehicle. But for the rapid discharge of rainfall a cross-fall is necessary. The problem is therefore to design the section in such a manner that the water shall be properly discharged with the least possible miximum fall. Suppose the least desirable inclination to be known, if this were adopted as the maximum inclination also, the profile shown with an exaggerated vertical scale in Fig. 1 would be obtained. This profile would be objectionable on the ground of appearance, and

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because the breasting would tend to wear hollow.

Having due regard, however, to these considerations, the figure should approximate as nearly as possible to straight lines, meeting at the vertex of the carriageway. If the vertex is slightly rounded, and the breasting still more slightly rounded, a profile is obtained approximating to a hyperbola, as in Fig. 2, and differing widely from the segment of a circle too often adopted, in which the crown is very level and the breasting unnecessarily inclined.

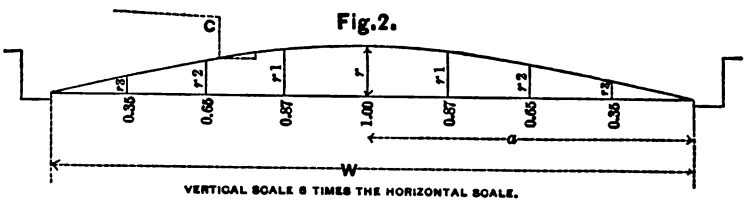
Let a=the horizontal distance from the vertex to the lowest channel in feet.

Let r=the rise of the vertex above the lowest channel in feet.

Let d=the difference of the levels of the two channels in feet.

Let w=the width between the channels in feet.

Fig.2.



For well-made impervious pavements

$$r=\frac{a}{36}$$

When there is a cross fall from channel to channel, the crown or vertex of the pavement is generally placed too near the center, and an unnecessary fall on the lower side is involved. In order that the inclination of the pavement on the two sides of the vertex may be the same, it is necessary to include only that portion of the curve in Fig. 2 which lies between the two channels, when the upper channel is placed in such a position c that the known ratio $\frac{w}{d}$ is maintained.

If $\frac{w}{d}=36$, the figure of the carriageway is half the above figure. If $\frac{w}{d}$ is greater than 36, the figure of the carriageway is greater than one-half of the above figure, and the fall is towards both channels. If $\frac{w}{d}$ is less than 36, the figure is less than half the above figure, and the fall is wholly towards the lower channel.

The height r_1 above the chord line, of a point at the distance $\frac{a}{4}$ from the vertex, should be 0.87 r.

The height r_2 above the chord line, of a point at the distance $\frac{a}{2}$ from the vertex, should be 0.65 r.

The height r_3 above the chord line, of a point at the distance $\frac{3a}{4}$ from the vertex, should be 0.35 r.

In order to apply these deductions to practice the curve in Fig. 2 should be drawn to a large scale for reference. For pavements without cross-fall the full curve is to be included. For pavements with cross-fall the upper channel c is to be so placed on the curve that $\frac{w}{d}$ in the street is equal to $\frac{w}{d}$ in the figure, and only the portion of the curve between c and the lower channel is to be taken.

It is thus a very simple matter to set out the cross section of any pavement to the proper curve, when the width between the channels and the difference of their levels are known; and if, in fixing the heights, foremen were always instructed to follow such simple rules, the minimum friction arising from lateral pressure in vehicles, consistent with proper water-discharging power of the pavement, would be attained. The fact that these objects are not always sought must be the author's excuse for bringing such simple matters before the Institution.

Having so designed the cross section of a carriageway, that without unduly increasing the traction, and wear and

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tear of vehicles owing to lateral pressure, water runs from it to the channels with maximum efficiency, it is important to consider the best mode of conveying that water to the sewer gullies. The best channels are heavy blocks of hard rock 12 to 18 inches wide, with at least one natural and perfectly smooth face. The slabs should be set upon concrete, with close-dressed joints filled with asphalt, and with a fall of $\frac{1}{4}$ inch per foot towards the curb, and not, as is sometimes done, with the same, comparatively great fall, as the breasting of the pavement, which tends to throw the wheels of vehicles against the curb. The lower edge of the pavement should be about $\frac{5}{8}$ inch higher than the upper edge of the channel. If constructed in this manner a longitudinal fall of 1 in 200 is sufficient to discharge the water rapidly.

II. COMPARATIVE ADVANTAGES OF VARIOUS CLASSES OF PAVEMENTS.

Much has from time to time been written on the relative advantages of various classes of pavements; but the elements necessary to make the statements comparable have always, so far as the author is aware, been absent. Light traffic, and much oftener heavy traffic, is spoken of; but the heavy traffic is often so called, because a few times in the year a heavy boiler or piece of machinery is drawn over it; and, in another case, because the carriageway is crowded with Hansom cabs and other light vehicles. The author has endeavored to formulate the question in such a manner that the results may be generally applied.

With reference to the traffic, the knowledge of three easily ascertained facts is necessary:

(*a*) The tonnage passing over the carriageway in twelve months.

(*b*) The width of the carriageway.

(*c*) The number of wheels on which the twelve months' traffic is borne.

Then $\frac{a}{b}$=the weight of traffic per yard of width, and $\frac{a}{c}$=the number of tons per wheel, giving a fair relative knowledge of the average kind of traffic in various streets.

With respect to the wear of a pavement, the following course should be adopted. If stone sets are in question, one or two rows of sets, the full width of the carriageway, should be taken up and weighed. They should then be carefully replaced, so as to be perfectly flush with the surrounding pavement, and at the end of twelve months again weighed. If the material is wood the exact measurement of a number of sets is sufficient. In addition to the information thus obtained, a street ledger should be kept, giving at a glance the cost per square yard of maintaining every pavement for each year. If, in writing of the relative durability of various pavements, this information were given, an immense amount of experience might be rendered generally available. Without some such information, any statements made can be little more than the opinion of individuals based upon impressions with respect to the traffic, which are by no means always correct.

About 300,000 square yards of stone pavement, constructed as described, have been laid within the last six years, in streets of varying traffic in Liverpool, up to 360,000 tons per yard width per annum, and an average of 0.923 of a ton per wheel including empties—two figures which, taken together, are probably not surpassed, if, indeed, they are equaled, by any other traffic in the world.*

The old pavements in streets of such traffic were generally of the hardest and most durable stone (A and B in the Table page 6), and the foundations, as already stated, of hand pitching; nevertheless, the pavements cost about 3*d* per square yard per annum to maintain, and they were never in good condition. The hard stone sets B and C, paved on concrete, and with impervious joints, remain in excellent condition. The oldest of these pavements, constructed in 1872, though subjected to a traffic of 218,000 tons per annum per yard of width, and a mean load of 0.679 ton per wheel, including empties, have hitherto cost nothing to maintain beyond the occasional filling up of joints with asphalt, and the restoring of a few sets, not

* The traffic given is that in the dock line of streets. In the average load of 0.923 ton per wheel, empties and light traffic are included.

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worn, but split and crushed by loads of 60 tons on four wheels.

The rate of wear under the greatest traffic has not exceeded 0.02 of an inch of solid stone per annum, except at junctions of streets and some other places, where very hard stones were avoided in order to prevent slipperiness.

Under a smaller traffic the macadam opposite the hospital in Great Howard street cost 3*s.* 6*d.* per yard per annnm to maintain, and would now cost 4*s.* 8*d.*; and in the same place wood costs the corporation, including graveling, 1*s.* 11*d.* per annum to maintain. The greater part of this is, however, paid to the company for maintenance, and really, therefore, includes a sinking fund.

These figures serve to show generally the great divergence in the cost of maintenance; but they do not include cleansing, the figures relating to which are still more favorable to the asphalt-jointed pavements. But a much more correct idea of the total difference of cost may be gathered from the table on page 252, in which first cost, renewal, and maintenance are all duly considered.

If the standard of traffic be taken at 40,000 instead of 100,000 tons per annum for every yard in width of carriageway, the figures for the last three pavements are as follows:

Description of Pavement.	Original Cost per Square Yard at Present Prices.	Deductions from first cost to determine cost of Renewal.		Interest on Original Cost at 4½ per cent. per Square Yard per Annum.	Sinking Fund Invested at 3 per cent. Compound Interest.	Maintenance per Square Yard per Annum.	Scavenging* per Square Yard per Annum.	Graveling per Square Yard per Annum.	Total Annual Cost per Square Yard.
		Cost of Foundation not requiring Renewal.	Allowance for old Materials at Date of Renewal.						
	s. d.	s. d.	s. d.	d.	d.	s. d.	d.	d.	s. d.
No. 6. Bituminous concrete pavement.....	3 9	Nil	Nil	2.0	Nil	0 9	2.4	..	1 1.4
No. 7. Wood pavement..	15 1.5	2 0	Nil	7.5	4.3	0 1.0	2.7	5.0	1 8.5
No. 8. Macadam pavement.....	6 9	Nil	Nil	3.4	Nil	1 0	8.0	Nil	1 11.4

* For the figures relating to the cost of scavenging, the author is indebted to Mr. R. S. Reynolds, M.R.C.V.S., who, as chief of the scavenging department in Liverpool, has given great attention to the subject.

While discussing the other comparative advantages of various classes of pavements, the total annual cost as shown by the foregoing Table should be borne in mind.

Pavement No. 1.—In this old form of Liverpool pavement the hard sets of the class A and B, when subjected to slow and heavy traffic, were invariably after a few years pushed from the vertical line, by the backward pressure of the horses' feet, through a considerable angle, often as large as 25°. As the sets on the two sides of the street were pressed in opposite directions, a wave line was assumed by each course. Instead of the whole upper surface of each set being duly presented to the wheels, each surface was therefore inclined, and the wear was confined chiefly to the upper edges. The effect of this in the production of noise may be readily conceived; but as such pavements, though cheaper in first cost, are shown by the foregoing Table to be more expensive than the best class of hard stone pavements, Nos. 2 and 3, it is unnecessary to refer to them further.

Pavements Nos. 2 *and* 3. — These pavements are now exclusively employed for the straight lines of heavy traffic in Liverpool, where the gradients are moderate, and the sets maintain the positions in which they are originally placed. For sometime after the asphalt was worn off the surface, the noise caused by the traffic is considerable, and horses appear much more liable to slip than at subsequent periods. The noise

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Table Showing the Total Costs of Various Pavements.

In this table the cost of maintenance and scavenging are reduced to a standard traffic of 100,000 tons per annum for every yard in width of the carriageway. It is assumed that the work is done by the corporation, and 8 per cent. of the cost of both labor and materials is included for establishment expenses.

Description of Pavement.	Original Cost per Square Yard at present Prices.	Deductions from First Cost to determine Cost of Renewal.		Interest on Original Cost at 4½ per cent. per Square Yard per Annum.	Sinking Fund Invested at 3 per cent. Compound Interest.	Maintenance per Square Yard per Annum.	Scavenging per Square Yard per Annum.	Gravelling per Square Yard per Annum.	Total Annual Cost per Square Yard.	Remarks.
		Cost of Foundation not requiring Renewal.	Allowance for old Materials at Date of Renewal.							
No. 1. Sets 7½ inches deep. Class of stone A, B. Gravel joints. Hand-pitched foundation.....	s. d. 12 1	s. d. 1 6	s. d. 3 0	d. 6.5	d. 1.8	s. d. 0 1.0	d. 4.2	d. Nil	s. d. 1 1.5	Old Liverpool pavements.
No. 2. Sets 7½ inches deep. Class of stone B, C, D, E, F. Asphalt joints. Portland cement concrete foundation.....	15 1	3 9	3 0	8.2	0.6	0 0.25	2.4	Nil	0 11.45	Pavement now constructed in Liverpool for heavy traffic.
No. 3. Sets 7½ inches deep. Class of stone B, C, D, E, F. Asphalt joints. Bituminous concrete foundation.....	14 10	3 6	3 0	8.0	0.6	0 0.25	2.4	Nil	0 11.25	Ditto ditto.
No. 4. Sets 7½ inches deep. Class of stone G, H, J, K, L, M, N. Asphalt joints. Portland cement concrete foundation.....	15 1	3 9	3 0	8.2	3.7	0 0.5	2.4	Nil	1 2.8	Pavement now constructed in Liverpool for light traffic, or steep gradients, and junctions of streets.
No. 5. Sets 7½ inches deep. Class of stone G, H, J, K, L, M, N. Asphalt joints. Bituminous concrete foundation.....	14 10	3 6	3 0	8.0	3.7	0 0.5	2.4	Nil	1 2.6	Ditto ditto.
No. 6. Bituminous concrete pavement.....	3 9	Nil	Nil	2.0	Nil	1 6.0	2.4	Nil	1 10.4	Pavement recently employed in Liverpool for back streets, and for street carriageways of very light traffic.
No. 7. Wood pavement, blocks 6 inches deep. Bituminous concrete foundation.....	15 1.5	2 0	Nil	7.5	10.1	0 1.0	2.7	5.0	2 2.3	Creosoted wood pavement, if constructed by Corporation.
No. 8. Macadam pavement, hand-pitched foundation.....	6 9	Nil	Nil	3.4	Nil	2 0.0	8.0	Nil	2 11.4	Now only employ'd in Liverpool for suburban roads.

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is due to the irregularities of the surface; and the slipping, though on first thoughts it may appear anomalous, is due to the same cause.

Cæteris paribus, a horse is less liable to slip upon a level unpolished surface with narrow joints, 3 inches apart, than upon the irregular surface of new hard stone sets. This may be partly due to the greater traction and partly to the uncertainty with which the horse feels the ground. In the North John Street pavement, the first of the class in question laid in Liverpool, this fact has been very obvious. For the first year of its life the pavement was strongly objected to by the carters on account of the slipperiness; but in this, as in all other cases, the complaints ceased when the larger projections had worn off. Owing, however, to the original existence of those projections, and owing also to the fact that many arrises are unduly broken off, the sets do not wear to so uniform a level as they undoubtedly would if the upper surfaces were better formed in the first instance. With the harder trap rocks and syenities the author believes that a more perfect pavement for heavy traffic than has yet been produced could be formed, if the upper surface of each set were roughly but uniformly dressed. The present method of wearing down the projections by the rolling contact of wheels in street traffic is certainly not an economical method; and if the smoothing were done at the quarries the objections which obtain to the use of such sets in many places, owing to the noise, and liability to slipping which they at first cause, would be in a great measure removed. The time required to wear down such projections, when the sets are properly held in position, may be judged from the fact that in North John Street almost every other set still shows hollows which originally existed in the surface, and which the wear of a total traffic in six-and-half years of about 1,417,000 tons for every yard in width has not yet reached. The difficulty of sufficiently dressing one surface of such sets by hand is no doubt very great; but the design of a machine for the purpose is well worthy of attention. The problem must not be confounded with that involved in the dressing of any ordinary rock, even the hardest used in building, or even with that of dressing granite for paving purposes.

Pavements Nos. 4 *and* 5 have been employed in Liverpool for light, quick traffic, or where the gradient is too great for pavements Nos. 2 and 3, and at the junctions of streets where, in turning corners, horses are more liable to slip. Each stone classed under this and the last head has its own peculiarities, which are explained, so far as possible, in the table at page 240. They all wear much more rapidly than those of the last class, but some of them, while absolutely free from slipperiness, wear flat, and retain their arrises. On this account they are remarkably suitable for quick traffic, and produce but little noise. The stones in this class wear so readily to a uniform surface, that it would not be worth while to dress their surfaces as is suggested in the last case.

Pavements Nos. 2 *to* 5 *inclusive* may be classed together with regard to cleanliness and traction. They are easily cleansed, and the result of a single sweeping is most satisfactory. They are remarkably free from dust in dry weather, and from mud in wet weather.

Some years ago, the author considered the desirability of testing the traction on various pavements by a dynamometer; but subsequent observation convinced him that such a course would only give misleading results. The work capable of being performed by a horse in drawing a load is dependent, not only upon the absolute power required to move the load at a certain speed, but also, and in a high degree, upon the uniformity of the resistance, and upon the ease with which the horse travels — depending again upon the uniform roughness, if the term may be applied, without such irregularities as cause uncertainty in feeling the ground.

The author decided, therefore, to draw his conclusions from a broader basis; and fortunately, the actual increase of work performed on the new pavements is so great, that there is no difficulty in doing this. It appears that in those lines of traffic in which pavements Nos. 2 to 5 inclusive have been substituted for pavement No. 1, the ordinary load of two horses has been increased by about 1 ton, and of one horse by about ½ ton. There is a

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general impression also that the speed even of the heavy cartage has been increased; if from no other cause, this is probably owing to the comparative absence of blocks in the traffic, for the speed of the quicker traffic is undoubtedly increased, and for a given traffic any given area of pavement is less crowded than before. The cost of maintaining vehicles is also stated to have been much reduced. It is difficult, however, to arrive at any absolute figures for the saving in wear and tear of horses and carts; but from the above data, taking the actual cartage rate of 1*s.* 6*d.* per ton, there is a saving in cost of cartage alone exceeding £10,000 a year for every mile of such a pavement as is now laid in the dock line of streets in Liverpool. This estimate can only be approximate; but the author is satisfied that if the wear and tear of horses and carts could be included, the £10,000 per mile would be found to be considerably less than the actual measure of the benefit, apart from cleanliness and reduction of noise and cost of maintenance, which the public derive from comparatively perfect pavements. In the streets of quick traffic the actual loads conveyed may not be greater, but there is certainly a reduction in the wear and tear of horses and vehicles, and an increase of speed.

The author has in this paper devoted much attention to the consideration of pavements for streets of heavy traffic, as he is satisfied that in most of the great forwarding towns such pavements have received too little attention. It is no uncommon thing to find in the heart of the heaviest traffic of large towns, both in this country and abroad, pavements constructed of boulders, or of sets so indifferently laid as to move under every passing wheel. The older pavements of Liverpool were indeed excellent as compared with many elsewhere. If the authorities of such towns took a broad view of the subject, they would at once see the great loss to the trade of the country in general, and of their own towns in particular, which the continuance of such pavements causes.

In connection with pavements for heavy traffic, the use of stone tramways,* such as those employed on London Bridge, has often been advocated. With the pavement No. 1, as formerly constructed in Liverpool, tramways of perfectly smooth Penmaenmawr rock have been largely used. The stones were 12 to 18 inches wide, and were appreciated by the carters; though, owing to the limited width of the carriageways, the number of standing carts, and the varying rates of the vehicles, constant diversions from the line took place. This inconvenience is not, of course, felt to the same extent on a bridge.

When the impervious asphalt-jointed pavements were introduced, stone tramways were in some cases again employed; but it soon became obvious that they were no longer appreciated; and it was by no means uncommon to see the horse walking on the tramway stones drawing a load with wheels on the sets. The difference in traction was, in short, no longer perceptible. Replies to inquiries made of the Liverpool Cartowners' Association, and other large carriers, have supported this view, and tramways have been discontinued in all ordinary cases. Stone tramways are the outcome of defective pavements. Under heavy traffic they are exceedingly difficult to maintain in a stable position. They induce exceptional traffic on the sets adjoining them, and therefore cause grooves to be formed. In crowded streets, even on bad pavements, their utility is but slight; while on good pavements they are worse than useless.

Pavement No. 6, of bituminous concrete is shown by the table to cost ultimately 1*s.* 10 4*d.* per yard for a traffic of 100,000 tons per yard of width. This is considerably more than stone set pavements, when laid in the best manner. It is not, however, suitable for streets of greater traffic than about 40,000 tons per of yard width per annum; and in such a street the annual cost of maintenance of bituminous concrete is so much more reduced than that of the stone pavements, that the prices become about equal, as is shown by the second table, where the standard traffic is taken at 40,000 tons per yard of width per annum. In every town, whether great or small, there are many streets of dwelling-houses through which only the local traffic passes, and for such cases this pavement is admirably adapted. Wheels

* Called in some towns "wheelers," with as much reason as stones to be broken for macadam are called "breakers."

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make as little noise upon it as upon rock asphalt, and horses' shoes make less; while it is moderately easy to cleanse.

Rock Asphalt Pavements.—In 1871 the author investigated the subject of the Val de Travers and other rock asphalts. If it had been possible to adopt asphalt pavements for any considerable section of the Liverpool streets, there can be little doubt that the system would have been commenced. Moderately level streets exist in Liverpool running north and south, but nearly all those running east and west have inclinations, upon which such pavements would be undesirable. Rock asphalt pavements have therefore not even been tried in Liverpool. It is to be hoped, however, that the experience of metropolitan engineers will enable a comparison between rock asphalt and other pavements to be made in the course of the discussion on this paper, on the principle adopted in the tables on pages 251 and 252.

No. 7, *Wood Pavement.*—To a number of energetic companies the successful introduction of wood pavements into this country is due. The stimulus given by the existence, or, in some cases, the fancied existence of several patents has initiated a work, which, under other circumstances, would probably have been long delayed. Beyond a keen and useful competition, however, the patented inventions have not, as a rule, produced any special advantages, and the best forms of wood pavement are now probably open to any one to construct. This being the case, the author has at pages 251 and 252 taken the cost of wood pavements, if constructed like the stone pavements of Liverpool by the Corporation. Even under these conditions it is clear that wood pavements must be regarded as luxuries when compared with the best stone pavements, though for traffic approaching or exceeding 40,000 tons per yard of width per annum they are less costly than macadam. Wood pavement, however, has not, in the author's opinion, been yet constructed in the best manner. When first introduced into this country, it was thought necessary to provide foothold for horses by keeping the blocks from $\frac{1}{4}$ an inch to 1 inch apart. The consequence was, that the fibers being spread by the traffic, absorbed impurities and wore away unduly. Experience has shown, however, that a close-jointed wood pavement, properly graveled, is not more slippery than a wide-jointed wood pavement also properly graveled. In the former the fibers cannot spread, and the little grains of quartz are much more firmly held in position than in the latter. Nor does it appear that creosoting makes the blocks when properly graveled more slippery.

Wood pavements having wide joints, or imperfectly laid upon yielding foundations, have properly been objected to on sanitary grounds; but between these and close-jointed pavements upon concrete foundations there is a wide distinction; and although creosote is of little use where the fibers are liable to spread, it would greatly diminish absorption if applied to the extent of 12 to 14 lbs. per cubic foot, where the joints are close and where the fibers cannot spread. Under the most favorable conditions, however, wood pavement cannot be so efficiently washed, or otherwise cleansed, as asphalt-jointed sets, or rock asphalt, though in this as in all other respects it is to be preferred to ordinary gravel-jointed stone-set pavements or macadam.

No. 8, *Macadamized Carriageways.*—Of all pavements macadam appears to the author the least satisfactory for street carriageways in which the traffic exceeds about 30,000 tons per yard of width per annum. It is the most costly, the dirtiest, and, on the average of all kinds of weather and all conditions of repair, probably involves a greater traction for a given load than any of the other systems when thoroughly well laid. Its dirtiness consists, not only in the excessive mud of wet weather, and the excessive and impure dust of dry weather, but also in the facility with which organic impurities are absorbed by it, decomposed within it, and exhaled to the atmosphere. In country, and in some suburban roads the extent of this objection is insignificant, and no other pavement is better than well maintained macadam; but in some of the carriageways of the west end of London one would regard it as intolerable, had it not been tolerated so long. To the unsophisticated provincial the manner in which, on a hot July day, fashionable London rolls over her tainted macadam pavements, apparently without even

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smelling them, is a mystery almost as great as surrounds the fact that the metropolis, alone among the great centers of civilization in this country, if not in the world, still submits with apparent satisfaction to an intermittent water supply, impure at times in almost every household, however pure the source of that supply may be, when with absolute pecuniary benefit a constant supply might be obtained.

ON AN INCLINED RAILWAY AT THE GIESSBACH, SWITZERLAND.

By R. ABT.

From "Abstracts" of the Institution of Civil Engineers.

THE cascade of the Giessbach, on the lake of Brienz, has of late years become a favorite resort of Swiss tourists, and to meet the demand for accommodation a large hotel has been built. This is placed on a cliff, about 303 feet above, and 1100 feet back from the lake, from which it is separated by the channel of the Giessbach, the approach being by a circuitous footpath on the right bank of the stream. In order to render the place more accessible, a concession was granted by the Swiss Government, in December, 1878, for the inclined railway described by the author.

This is a single line, with a middle crossing place, on the meter gauge, with a central rack rail. The average gradient is 28 in 100, rather more than half the total length (187 meters out of 346 meters) being carried upon a wrought-iron bridge of five spans of 38 meters each. These are arched trusses; the roadway is carried by a straight [iron beam, weighing 28.23 kilogrammes per meter, above a segmental arch of ⊥ section of 27.25 kilogrammes per meter; the two members, which are 6.20 meters vertically apart at the springing, and 1.07 meter at the crown of the arch, being united by struts and diagonal ties of [iron, from 13 to 9 kilogrammes per meter. The roadway is formed of ⌐⌐ iron (*zores*) cross beams, 15.5 kilogrammes per meter, placed at intervals of 1 meter, which carry the plank footway, 60 centimeters wide, besides doing duty as sleepers for the rails. The crossing place for the carriages is on the bottom span, which is therefore wider and heavier than the others, its total weight being 18 tons, or 0.497 tons per lineal meter; the other four spans weigh respectively 15.6, 11.8, 11.8 and 10.6 tons, making a total of 68 tons for the whole bridge. The piers and abutments are in dressed masonry. The rails are of wrought iron, flat-bottomed, and weighing 16.75 kilogrammes per meter. On the bridge they are attached by cast-steel shoes clipping the flanges to the iron cross sleepers. When the line is in earthwork, oak sleepers, and iron spikes of the ordinary pattern, are used. The rack rail is made with] iron sides, and teeth of trapeziform section, having a pitch of 101 millimeters riveted through them. It is put together in segments of 3 meters long, weighing 96 kilogrammes, or 32 kilogrammes per meter, and is carried by continuous longitudinal beams of ⌐ iron over the wooden sleepers.

The traction is on the water-balance system, the descending carriage drawing up a second loaded one by means of an excess weight of water carried in a tank in the under frame, the two being united by a steel wire rope passing over a reversing pulley at the upper end of the line. The rope weighs 700 kilogrammes; it is made of the best English cast steel, of a total section of 2,198 square millimeters in seventy wires, of 2 millimeters diameter; has a breaking strain of 30 tons, or about 150 kilogrammes per square millimeter. The carriage is about 11 meters long, divided into six compartments, one for luggage, and the other five with seats for forty passengers; it is carried on six wheels, of which the two uppermost are a transverse axle carrying the toothed wheel and the brake drum; while the other four are attached to a

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bogie frame of 2.2 meters base below. The distance from the center of the bogie to the upper axle is 4.5 meters, giving a total wheel base of 5.6 meters. All the wheels have bronze bearings and run loose on their centers. The brake drums are of cast steel, 52 centimeters diameter, and the brake blocks of bronze. A safety catch, formed by a toothed rod, is attached to the coupling hook, which, in the event of the rope breaking, falls into the hollow of the rack rail and stops the carriage. The wheels of one carriage are flanged on the inside, those of the other on the outside, of the rail; so that, on arriving at the crossing point, one invariably goes to the right and the other to the left. The total weight of the carriage empty is 5.3 tons; the capacity of the water cistern is about 5½ tons.

The load to be lifted varies from 6 to 9½ tons, which corresponds to a descending counterpoise of between 7.3 and 10.8 tons, or the amount of water expended at each trip may vary between 1.6 tons and 5.8 tons. The latter quantity can be filled and discharged in about a minute.

The maximum speed allowed by the concession is one meter per second, making 346 seconds, or about 6 minutes for the trip; a speed which, the author remarks, may be considered as somewhat snail like, but nevertheless, when compared with that of the Swiss lines, with with the ordinary valley gradients of about 6 in 1000, represents a comparative duty; the 93 meters of vertical height corresponding to a length on the lower gradient of 15.6 kilometers, and to traverse this in 6 minutes a speed of 156 kilometers per hour, or double that of the fastest express train in England, would be required. About 4 minutes are required for the necessary operations of loading and unloading the carriage at either end; so that the trains succeed each other at intervals of 10 minutes during the working season, which lasts from 15th June to 15th September usually.

The works of the line were commenced at the end of October, 1878, and the line was opened for use on the 20th of July following. The cost is stated at 146,880 francs, and the annual working expenditure at 3,640 francs. At the close of the first working season on the 30th September, 1879, one thousand eight hundred trains had been run, carrying twenty-eight thousand persons without the slightest accident. The total receipts were 18,300 francs, equal to a gross return of 9.97 per cent. on the capital, or allowing 5 per cent. as interest, and 4 per cent. as a reserve fund for renewals, there was nearly 1 per cent. surplus, apart from the amount saved in transporting provision, stores, coal, and other heavy articles to the hotel.—*Die Eisenbahn.*

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS—The latest Number of Transactions contains:

Paper No. 212. "The Strength of Wrought-Iron Columns," by G. Bouscaren.

Paper No. 213: "The Improvement of the Harbor of Quebec," by J. Vincent Browne.

THE ENGINEERS' CLUB OF PHILADELPHIA. At the last meeting the Standing Committees of the Board of Directors for 1881 were appointed as follows:

On Finance—Frederic Graff and J. J. de Kinder; *On Membership*—J. J. de Kinder, Geo. Burnham, Jr.; *On Publication*—Rudolph Hering, Geo. Burnham, Jr.; *On Library*—T. M. Cleemann, Fred. Graff.

Mr. Morris exhibited a photograph of a machine designed by Mr. Wm. S. Auchinchloss, which will solve problems of various kinds, involving proportion, alligation, involution, evolution, etc.

Mr. Charles A. Ashburner, Chairman of Committee on Information, presented a paper upon the progress and methods of the Pennsylvania State geological survey. Forty-eight counties have been entirely completed, eighteen counties partially surveyed and seven counties remain to be surveyed. The Board of Commissioners estimate that it will require three years to complete the survey of the entire State. He also read notes on mine topography, in which a new method was proposed for determining the area of the available coal in the anthracite region, and cited an instance in which the hypothesis of the method had been sustained by after developments. He also exhibited a complete set of specimens of the crude and refined petroleums from Barku, Galicia and other European fields, recently received through Hon. Lewis Emery. He also presented a paper by Colonel James Worrall, member of the club, upon the routes and methods which have been proposed for crossing the Isthmus. The Panama, Nicaragua and Tehuantepec canal routes and the ship railroad of Captain Eads were treated, forming a paper too comprehensive to be fairly treated in a short abstract.

Mr. T. M. Cleemann read a paper on the

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strength of wrought-iron columns, showing that the accepted formula of Rankine & Gordon gives imperfect results, and urging the necessity of further experiments on various shapes in order to complete it and render it more exact. Professor L. M. Haupt read a paper on intercommunication in cities, showing the great value of increased facilities of travel, and applied them specially to Philadelphia. The number of persons using the horse cars during the last year was about one hundred million, and the value of a saving of one mile in distance, and its equivalent in time and power, was computed upon this basis, with some surprising results. The paper was limited to a consideration of the street system only, the railroad system being reserved for the future. The paper contained some valuable suggestions as to important proposed improvements.

ENGINEERING NOTES

THE Leggestein tunnel, near Wasen, the first curved tunnel on the St. Gothard line was completed on the 16th inst. It is 3,280 feet long, and has been bored through hard granite entirely by hand labor, as, owing to the absence of water power, perforators could not be used. The contractors are profiting by the present fine weather to hasten the completion of the works, which are progressing much more rapidly than was expected at the beginning of the winter.

THE Severn tunnel works are being pushed forward with great energy. Four hundred men are employed, and the large pump, specially made for the purpose from the instructions of Mr. Richardson, C. E., is now throwing about 3,700 gallons of water per minute. It is hoped that the underground works will shortly be freed from water. Upon the Gloucestershire side a small portion of the masonry of the tunnel has been completed, and Mr. Walker, the contractor, is getting the work well in hand.

ON Saturday last an interesting experiment was concluded at the new iron quay in course of construction for the Great Eastern Railway Company at Ray Island, Harwich. In the beginning of last spring a number of iron screw piles, which had been placed in position, but not braced together, were overturned by a slip of the earth embankment immediately behind them, and it has been found necessary to remove these and replace them by others. It was with this object that on last Saturday week Mr. G. N. Abernethy, the resident engineer, accompanied by Lieut. W. Almack, R. N., of H. M. S. Penelope, proceeded to attempt to remove the large screws, 4ft. diameter, which form the base of the pile. This was done by firing a 1 oz. charge of "tonnite" placed in the interior of the pile at a depth of 36ft., and ignited by electricity, it being found impossible, on account of the accumulation of mud in the pile, to insert the charge any lower, the piles actually being 48ft. long, and imbedded 37ft. in the mud of the river. The experiment was successful, and on Saturday last the pile, 36ft. long, 2ft diameter, and 1in. thick, was drawn by Mr. T. Vaux's powerful tug, and landed on the quay, when it was found to be neatly fractured at the point of discharge. The tonnite, manufactured by the Gun Cotton Company, is a comparatively new explosive, and is said to be much more safe for use and transport, and equally as strong as dynamite.

THE PROPOSED NEW TAY BRIDGE.—As already mentioned, the plan adopted for the restoration of the Tay Bridge involves the complete abandonment and removal of the existing viaduct. The structure to be substituted for the abandoned bridge will be erected a little higher up the river, and will carry a double line of rails. It is understood that the engineer has devised a remedy for the objection raised last year to the junction of the Newport Railway with the bridge line, and that the other recommendations of the Special Committee will be given effect to, so that all opposition to the Bill intended to be introduced next session may be avoided. The cost of the works will be very considerably greater than was anticipated in the application to the Parliament made last session; but the arrangements contemplated are such as, it is believed, should remove all doubts as to the absolute stability of the new structure.

THE SUEZ CANAL.—The revenue of the Suez Canal Company has made a great bound upwards this year. The total receipts to August 31, were £1,100,820. The corresponding revenue in the corresponding period of 1879 did not exceed £800,764.

IRON AND STEEL NOTES.

IRON MANUFACTURE: ENGLISH AND AMERICAN.—The *Engineer*, in an editorial article on general progress in 1880, says of the iron trade:—Our great competitor is the United States. In that country iron ore and coal abound, and the production of manufactured iron and steel of all kinds has been greatly developed and fostered by protection. We regret to say that some of our own ironmasters and others prognosticate that in a comparatively short time the United States must adopt free trade; that when this is done there will be great demand for British iron and steel, and that if we can only rub along a little longer we shall yet do very well without making undue exertions. We have heard this argument used year after year for many years. It is fortunate that no matter what turn men's thoughts take in this direction, their actions do not run wholly in the same groove. There is not the slightest probability now that there will be any mitigation of the tariffs in our favor until the next presidential election, four years off. Those who hold different opinions assert that the farmers will rise against protection; but the truth is that the American farmers suffer very little, if at all, from high import duties. The American farmer has practically no rent

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to pay, and he can therefore very well afford to contribute to the prosperity of large towns by submitting to the infliction of the tariff. At this moment the United States are the most prosperous nation on the face of the earth; they are practically self-sufficing, and it is very difficult to see what they could gain yet awhile more than they have by adopting free trade principles. There is in truth no analogy at all between such a country as America and such a country as Great Britain. The facts being as they are, ironmasters in this country ought to see that no effort should be spared to put themselves on a footing of equality with their competitors. It is quite certain that at present we are not holding our own in this respect. The United States ironmasters are beating us by 100 per cent. in the output from their plant. With one pair of converters they can do as much and more than we can do with two pairs; and while our blast furnaces turn out 480 tons of pig per week, theirs, much smaller, give as much as 1,100 tons a week. In the rail mills, and bar and sheet mills, matters are in much the same condition. If we are asked, To what is this superiority due? we reply that it is to be traced, to some extent, to better organization, and in others to better plant. In the Bessemer works, for example, the drill of the men employed is perfect, and a converter is never stopped for days while being lined up and re-bottomed. The converter alone represents but a small part of the plant; but when a converter is standing, so, to a certain extent, do the blowing engines, the hydraulic appliances, ingot molds, and very probably the hammer, the cogging mill, and the rail train. What would be thought of a foundry which was closed while a 5-ton ladle was being relined? In the United States, for a long time back, the moment a converter is burned out it is taken away, and a new one put in its place. The operation requires, we understand, about half-an-hour at the most. In how many English steel works is the same plan pursued? It has, we may say, been forced on Messrs. Bolckow, Vaughan & Co., by the necessities of the basic process, and we hope to see it generally adopted before many months are out. There is still room for invention in this direction. Bessemer plant was regarded as perfect until the other day among ourselves. Then Mr. Holley showed the good people of the States that, excellent as it was, it could be made better. Is it to be supposed that Mr. Holley has left our own Bessemer steel men nothing to do? We think not. Mr. Windsor Richards, in his recent address to the Cleveland Institution of Engineers, spoke in somewhat depreciatory terms of the work done by the Edgar Thomson Steel Company, suggesting that by hard driving, the furnaces were soon burned out and wanted re-lining. Even if we admit this to be quite true, it seems to be perfectly clear that the cost of relining must be charged as so much per ton of iron made, and that unless it can be proved that the Edgar-Thomson furnaces cost more for repairs and renewals per ton of pig than do furnaces less hard pressed, the advantage is *altogether* with them. To make this plain, let us say that one of our great Cleveland furnaces, with its appurtenances, cost £20,000, which is not far from the truth. It turns out, say, 450 tons of pig iron per week, or 23,400 tons a year. The interest on £20,000 at 5 per per cent. is £1,000, or 20,000 shillings; consequently each ton of pig iron must be charged with, say, 10d. for interest alone. If, however, the make of the furnace had been doubled, or 900 tons a week, then 5d. a ton would have been saved, and this sum, and less, represents in the present day a profit which is by no means to be despised. It comes to nearly £20 a week per furnace, and even this amount of clear profit, small as it is, many an ironmaster would be glad to get from each of his blast furnaces. It may be said that, after all, the rate at which a furnace is driven has very little to do with mechanical engineering. But this is not true; double production means double blowing, double feeding, double hoisting of materials, and increase in the power of various appliances, all of which demand renewed exertion on the part of the mechanical engineer. And here we may refer to a somewhat novel pair of blowing engines, recently put down at Staveley, where they were constructed from the designs and under the superintendence of Mr. Charles Markham. We shall illustrate these engines in an early impression, and it will be enough now to say that they combine in an unusual degree great power with considerable economy of fuel and very small first cost. A great deal of the blast furnace plant of Great Britain is antiquated, and the sooner it is replaced with more modern plant the better. We may cite as an example hot blast stoves. It is a suggestive fact that much of the success which attends the labor of the American ironmaster is due to the efficiency of Mr. Cowper's stoves, and yet English ironmasters have been very slow to accept an invention which American ironmasters jumped at.

THE STEEL TRADE.—The great increase in the manufacturing capacity both of Europe and America has alone prevented that return to high prices which the present demand would have caused; and as, on both sides of the Atlantic, factories are being still further extended, the same counteracting cause will have effect for some time to come. A year ago, the total output capacity of steel rails in England was rather more, and in America rather less, than 750,000 tons per annum, while now, with the works already in operation or ready to commence at short notice, the total in each country is about a million tons. In America the present demand for steel rails is so considerable as to tax severely the supplying power available, and the product for at least six months forward is already sold. A deficiency does not at first result in the importation of rails from Europe, but in the supplementing of that department of manufacture which falls behind. Thus, while the demand for raw material is generally sufficiently met by Italian or Spanish ores, Bessemer pig iron has to be imported when the local blast-furnaces prove insufficient, and,

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in other cases, when the blooming mills cannot keep pace with the converters or with the rail mills, a considerable import of blooms from Europe takes place. This is the case at present, not only for rail making, but also for supplying those smaller steel works which make plates, wire, and other miscellaneous goods, with the blooms and billets the large converting works are at present too busy to supply. If the rail mills in America cannot meet the demands of purchasers during the coming year, it is yet an open question whether the deficiency will be made up by imported steel rails, or by home-made iron rails, or by iron rails from Europe. Both in Europe and America the different modes of making steel are finding their proper place. The Siemens process, with all its acknowledged merits, cannot compete with the quicker Bessemer converters for so cheap a commodity as steel rails. In England, steel works constructed with the Siemens open-hearth plant are not working on rails, but are making ship plates, railway tires, axles, and other similar articles, or are stopped altogether; while in America the Siemens process has hardly been applied at all to rail making, and the Siemens furnaces, with or without the Pernot modification, are confined entirely to the smaller industries, and are found extremely convenient for using up the Bessemer scrap. Both in England and America the circumstances of locality and transport are acquiring enhanced importance in the competition of trade; but while in England even a short land carriage is a disadvantage, in America works unfavorably situated for material are compensated by their contiguity to local consumers.—*Matheson and Grant's Engineering Trades' Report.*

RAILWAY NOTES.

NINETY MILES AN HOUR BETWEEN PHILADELPHIA AND NEW YORK.—At a recent regular meeting of the Franklin Institute in Philadelphia, W. Barnet Le Van read a paper on "Ninety miles in sixty minutes; or, how to accomplish the distance between New York and Philadelphia in one hour." It was a continuation of one read by him some time ago on high railroad speeds, and undertook to show the difficulties in the way of running trains at this high speed at present, and how they could be overcome. In the paper the distance in an air line between New York and Philadelphia was stated to be 80.09 miles, over a comparatively level country. The existing roads are far from being straight. On the Pennsylvania line, in the 88.4 miles between Philadelphia and Jersey City, there are 84 curves (15 in the 15 miles between Germantown Junction and Schenck's). The greatest length of straight track—between Philadelphia and Trenton, does not exceed three miles, and the greatest in the entire road does not exceed 10 miles. The Pennsylvania Railroad is not responsible for this condition of the road, but has in fact done much to straighten the line, and, notwithstanding these drawbacks, runs trains on the road at the rate of 50 miles per hour. On the Bound Brook Route there are 43 curves; one on the bridge crossing the Delaware River, which has a radius of 2,865 feet, is 1,837 feet long, and ascends 19 feet to the mile. The greatest stretch of straight track is from Skillman's east—14 miles. To compensate for the centrifugal force tending to throw the cars from the track when running at high speed on curves the outer rail has to be raised. On a curve of three degrees radius, the super-elevation required on a guage of 56½ inches, while less than five inches at 50 miles an hour, would have to be 16 inches at 90 miles per hour. On the Pennsylvania road the super-elevation is one inch for each degree of curvature up to five inches, which is the limit. The speed must be reduced beyond that to correspond with the curve. This is one of the limitations put upon high speed on existing roadways. Mr. Le Van considered others at great length, and summed up by saying that, after a careful study of the subject, he was satisfied that a paying road could be built to be run in a straight line between New York and Philadelphia, reducing the distance about 10 miles and enabling trains to be run through in 60 minutes. One of the means of effecting this purpose would be a reduction of the dead-weight in the trains. The fast trains now running between Philadelphia and New York have generally four cars with engine and tender, weighing 232,000 pounds, or 116 tons dead load, and are 264 feet long. For from four to eight tons of passengers carried, trains are made up weighing from 110 to 150 tons. Mr. Le Van thought it would pay to build a line so perfect in all its details as to exclude rival lines, and attract to itself all the through business. The line he pictured crossed no roads at grade, and had only two curves of 10,000 feet radius each.

ST. GOTHARD RAILWAY,—An account of the Leggestein spiral tunnel, which is one of the most remarkable works in connection with the St. Gothard Railway, has been communicated to the *Daily News* by the Geneva correspondent of that paper.

"The leading feature of the scheme adopted by the engineers in constructing the line has been to keep to the bottom of the valleys—on the north side of the Alps, the valley of the Reuss; on the south side, that of Ticino—and, so long as they did not deviate too widely from the required direction, to follow their windings until the point fixed for the entrance of the great tunnel should be reached. When this could not be done, and it became necessary to carry the railroad higher spiral, or to use the German term, 'turn tunnels,' were to be pierced through the mountains. These tunnels made at once a steep gradient and a sharp curve. The gradient of the Leggestein tunnel is 23 in the 1,000, and it describes a curve of 300 meters. After leaving it, the line winds spirally outside the mountain, and passing through a shorter passage higher up, reaches the required altitude. The construction of this tunnel was difficult, less on account of its length, which is nothing extraor-

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dinary, than owing to the necessity of boring entirely by hand through a mass of almost impenetrable granite. The progress made at the outset did not exceed three decimeters (twelve inches) in twenty-four hours, even with the aid of blasting. The necessity of handwork arose from the absence of water, and the impossibility, in the circumstances, of using steam for the perforators. Two other turn tunnels—in the valley of the Reuss—that of Wellington, 1,000 meters long, and that of Pfaffensburg, 1,000 meters long—will be completed during the coming spring. The former, like the Leggestein, is being bored by hand, the latter by water power. On the south side, in the valley of the Ticino, there are four tunnels (which are to alpine railways what locks are to canals), of from 1,500 to 1,600 meters long, now in course of construction. All these are being bored by water power, and like those on the north side are expected to be finished early in 1881. It is intended to light the great tunnel by electricity. To this end two systems have been proposed. One is to place in the passage 40 electric lamps, each possessing a capacity of 1,200 candles. The interval between each lamp would be about 400 yards, and the necessary motive power would be supplied by the turbines at Airolo and Goeschenen, which have been used for moving the perforators and ventilating the workings. The second proposal, whether it be practicable or not, has certainly the merit of greater originality. According to this scheme, a locomotive impelled by compressed air would be stationed at either portal of the tunnel. These locomotives, being smokeless, would be used for drawing the trains through the tunnel. Each locomotive would carry two electric lamps, and two would be placed at the end of the train, together with reflectors, so arranged that their united light would be equal to that of 12,000 candles. By this means, wherever there was a train, and for a considerable distance before and behind it, the tunnel would be brilliantly lighted at a comparatively trifling expense, the electricity being produced and the engines provided with their motive power by the turbines at Goeschenen and Airolo."

ORDNANCE AND NAVAL.

RESULTS OF EXPERIMENTS AT CRONSTADT WITH A 9-INCH MORTAR AGAINST AN ARMOR-PLATED PLATFORM, OR HORIZONTAL TARGET.—The shape of the platform was rectangular, 70 ft. in length by 35 ft. in breadth, and it was composed of two layers, each consisting of 50 plates, the thickness of the upper layer being 2 inches, and that of the lower 1 inch. The two layers were united by rivets 1.13-in. in diameter.

Under the plating, and in the direction of its breadth, were placed baulks 8.4-in. square at a distance of 3 ft. 5 in. from center to center, to which the plates were bolted by means of conical-headed bolts 1.13-in. in diameter. Under the baulks were three longitudinal beams 8.4-in. square. At the points of intersection of these with the transverse baulks, the bolts served to connect them as well as the plating together. These beams rested upon sleepers of the same section which were supported upon 50 piles 15.7-in. in diameter, driven 5 ft. into the ground. The total height of the mass from the ground to the upper surface of the plates was 5 ft. 11 in.

The 9-in. rifled mortar of steel, loading at the breech, was placed behind a parapet in such a manner that an artificial alignment was needed to lay it by. The weight of the mortar including the breech fastening is 114 cwt. The maximum charge is 18 lbs., giving a range of 5,400 yards at an elevation of 45°.

It was mounted on a provisional iron carriage, on the Semenoff principle. The elevation was effected by means of toothed wheels. The distance of the mortar from the platform was 2,432 yards.

Three kinds of projectiles were fired—ordinary cast iron, hardened cast iron, and hammered steel.

The weight of the first was 271 lbs. The shells of hardened iron were loaded with sand to a weight of 278 lbs., or with powder to 280 lbs. In the latter case the bursting charge did not exceed two lbs., and the weight was made up with lead.

The steel shells were fired either quite empty, and weighing on an average 265½ lbs.; or loaded with from five to six lbs. of powder, to bring them up to a total weight of 271 lbs.

A trial of five shells of ordinary metal proved the laying of the mortar, and determined that for an elevation of 45° the proper charge was 8.36 lbs.

Of the following 36 shells of ordinary metal, none hit the mark. Increasing the charge to 8,59 lbs., out of six shots at an angle of 44° there were two hits, but their effects were very small, and the two projectiles were broken to pieces.

Next were fired 28 shells of hardened metal, at an angle of 51°, with a charge of 9.94 lbs. There were five hits out of these in spite of very unfavorable atmospheric conditions.

The effects were considerable; the two layers of plates were penetrated, even when the projectile encountered a baulk. The bolts were broken and the timber work damaged, but in most instances the shells broke up.

Steel shells empty were then fired with a charge of 9.94 lbs., at an elevation of 57°. Three shells out of eight hit. The effects were much superior to those obtained with the hardened metal shells, although the weight of the latter was greater. The projectiles after penetrating the plates, retained a greater velocity, and remained entire.

Nine shells of hardened metal were then fired with the same charge and at the same elevation as the weighted shells, loaded with 2.25 lbs. of powder. Three struck the platform. The effects were similar to those of the weighted shells, the projectiles broke up before the bursting charge could explode.

Four steel shells out of nine, with bursting charges of from 3.6 lbs. to 5.4 lbs., fired with charges of 9.94 lbs., at an elevation of 57°,

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struck the target. Only one burst, and scattered its fragments beneath the plating.

Some were of opinion that the bursting charge was insufficient, or that the thickness of metal should be reduced, so as to afford a larger internal space, and at the same time a better chance of inflaming the charge by the shock. Others believed the explosion to be due to the shock and the friction of the grains of powder against the sides of the projectile only, and that if the charge did not burst, it was owing to deficient velocity of the projectile at the moment of impact. The heat developed by the blow, reaches immediately to a very slight depth in the thickness of the projectile, and to make it penetrate as far as the powder it would be necessary to reduce the thickness of metal to a degree incompatible with strength, especially when a cheap description of steel is made use of in the manufacture.

The Committee were of the opinion that nothing would ensure bursting but a percussion fuse in the base of the projectile. But this arrangement would only prove advantageous with a large interior charge, and the quality of steel which it is proposed to employ does not admit of greater internal capacity than is possessed by the shells of hardened metal. There is, therefore, no room for researches in this direction.

The Committee concluded that it is simply advisable to abstain from placing the bursting charge in a cartridge in the case of mortar shells, as the velocity on impact of these projectiles is less than that of shells fired point blank against armored surfaces, and there is no fear of their exploding before penetrating the armor.

Further, the ammunition for mortars for coast service should consist of an equal number of shells of steel, and of hardened metal.

One of the members of the committee, Colonel Spitzberg, entered on the minutes his personal opinion that a percussion fuse would be of great advantage in the case of projectiles containing small bursting charges, whether made of hardened metal or of steel; as the effect of mortar fire against the weakest part of a ship would be considerably augmented thereby.

The experiments of Volkovoié-polé with 8-inch shells, furnished with percussion fuse at the base, have already given satisfactory results.

Colonel Spitzberg proposes that the same arrangement should be applied to the shells of the 9-inch mortar whether made of hardened metal or steel.

BOOK NOTICES.

Publications Received.

Official Gazette of the United States Patent Office. Vol. 19, Nos. 5 and 6.

A Lecture on the Improvement of the Danube at Vienna. By Sir Gustave v. Wex. Translated by Maj. G. Weitzel. Washington: Government Printing Office.

Modern Architectural Designs and Details. No. VI. New York: Bicknell & Comstock.

This work continues to afford valuable aid to working architects.

Report of the Board to Recommend a Standard Gauge for Bolts, Nuts and Screw Threads for the United States Navy. Washington: Government Printing Office.

Papers Read before the Pi Eta Society of the Rensselaer Polytechnic Institute. Vol. 2, No. 1. Troy: Lisk & Barnum.

Transactions of the American Institute of Mining Engineers. Vol. VIII. May, 1879 to February, 1880. Easton: Published by the Institute.

Les Principales Applications De l'Electricite. ParE. Hospitalier. Paris: G. Masson. For sale by D. Van Nostrand. Price $3.50.

Only a single chapter of this royal octavo is devoted to Electric Batteries and their applications. The remainder of the work is devoted to Thermo-electric, Electro-dynamic machines, Electric Lights, Telephones, and Microphones.

The illustrations are on a liberal scale and of superior quality.

A Simple Treatise on Heat. By W. Mattieu Williams, F. R. A. S. London: Chatto & Windus. For sale by D. Van Nostrand. Price $1.00.

No modern writer knows better how to write a brief popular treatise which shall at the same time be scientific than Mr. Williams.

He has here presented the common facts learned by observation, and the facts also that have been reached by laborious and skillful experiment.

The proper arrangement of these facts without particular reference to molecular motions constitutes the science of heat as present in this simple treatise.

Sir William Herschel—His Life and Works. By Edward S. Holden. New York: Charles Scribner's Sons. For sale by D. Van Nostrand. Price $1.50.

This brief memoir sets forth with earnestness and enthusiasm the claims of the great astronomer to the regard of scientists of today. The position of the author will cause his estimate of Herschel's attainments, either as a physicist or astronomer, to be received with respect everywhere. The book will prove an acceptable contribution to biographical literature.

Engine-Driving Life. By Michael Reynolds. London: Crosby, Lockwood & Co. For sale by D Van Nostrand. Price $1.

In former times it was the sailor who furnished the dramatic situations for the popular tales. Out of quite an ordinary experience for his profession, the mariner was always ready to supply the demand for truthful accounts of imminent peril, hair-breadth escapes, and safety secured by coolness and presence of mind in the face of great danger.

This little book bears assurance that the sailor can no longer monopolize the situation. Travel by land has its perils as well as travels

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by sea ; and for every situation on ship-board requiring instantaneous brave action in which life is risked, the locomotive furnishes an incident to surpass it.

It is a new record of human experience, and is worth reading.

ELEMENTS OF ASTRONOMY. By ROBT. STAWELL BALL, LL. D., F. R. S. Text Book of Science. For sale by D. Van Nostrand. Price $2.25.

This is a popular treatise in so far as that the reader is expected to understand only the elements of Algebra and Geometry for a complete mastery of it. It is intended for beginners, but it is believed by the author that even advanced students may read it, particularly the latter portions, with profit.

The contents include in separate chapters the following topics:

Chap. I.—Astronomical Instruments.
" II.—The Earth.
" III.—The Diurnal Motion of the Heavens.
" IV.—The Sun.
" V.—Motion of the Earth around the Sun
" VI.—The Moon.
" VII.—The Planets.
" VIII.—Comets and Meteors.
" IX.—Universal Gravitation.
" X.—Stars and Nebulæ.
" XI.—Structure of the Sun.
" XII.—Astronomical Constants.

The illustrations are good and abundant.

ODONTORNITHES: A Monograph of the Extinct Toothed Birds of North America. By O. C. Marsh. For sale by D. Van Nostrand. Price $12.00.

This fine quarto is designed for scientific readers only, and will be read with care by paleontologists alone.

The popular mind will experience some pleasure in learning of the exclusive possession by this country of the remains of toothed birds, but lovers of science will regard with admiration the evidence of a high order of attainment in a confrere, and will see nothing to regret in the mechanical execution of this new addition to American scientific literature.

TRAITE DE CHIMIE: By Paul Schützenberger. Paris: Librarie Hachette et Cie. For sale by D. Van Nostrand. Vols. 1 & 2, price $11.20.

Only two volumes of this fine work are as yet published. The complete work will fill six royal octavo volumes. It presents general Chemistry, Chemical Physics and Chemical Technology as inseparable parts of one branch of science.

The illustrations are numerous and of unsurpassed excellence.

The order of arrangement is the one founded on atomicity of the elements.

CHAUFFAGE ET VENTILATION DES LIEUX HABITES. Par P. Planat. Paris: Ducher et Cie. For sale by D. Van Nostrand. Price $10.50.

To know how vast a subject is that of Heating and Ventilation, it is necessary to turn over the leaves of this ponderous volume. Nothing bearing, in any way, upon this subject can have been omitted, and yet nothing seems to have been treated with unnecessary fullness.

All plans and devices are treated with that careful regard for clearness of exposition which is characteristic of the French scientific writers.

RANKINE MEMORIAL VOLUME: with Biographical Sketch. By Professor P. G. Tait. Editor, W. J. Millar, C.E. London: C. Griffin & Co. New York: D. Van Nostrand. Price $10.00.

The volume containing selections from the writings of the late Professor Rankine now before the public, was originally proposed not long after the death of the lamented author of the papers, but from various causes was delayed. We are glad, however, to congratulate the publishers on the appearance of the volume, more especially at a time when the higher and more exact education in scientific principles is being recognized as the foundation of all true knowledge of our physical surroundings.

The loss to scientific and engineering culture through the death of Professor Rankine can only be fully appreciated by those who are most intimately acquainted with him, and who had the privilege of hearing his lectures, or were associated with him in his various pursuits as an engineer and a man of science. Some of these characteristics the editor and biographer have given us in the introduction to the volume, and not the least notable of these was the extreme clearness and precision with which Professor Rankine stated his opinions and the breadth of view which he adopted.

Professor Rankine's Manuals have now been published for a number of years, and have gone through many editions, and are recognized as most valuable compendiums of engineering science quite unique of their kind. They are confessedly hard reading for a great number, especially to those who have not had the privilege of hearing the master himself expound in the lecture room, and were possibly to some extent before their time, as the exact habits of thought required to follow with advantage the teaching of these books could hardly be looked for amongst those actively employed in the every-day routine of the engineering profession. The development of chairs of engineering in our universities, and of classes for the study of mechanics and engineering subjects in our various institutions, during the period since Professor Rankine himself began to lecture, has, however, caused an increased demand for books of a higher class, whilst the growing influential status of the engineer in all the branches of the profession, combined with the various movements at present on foot for the proper organization of technical instruction in the arts, point conclusively forward to the demand for high-class works treating of the principles upon which all such practice must depend.

The present memorial volume contains selections from the various papers which the late professor so profusely supplied to our various scientific and engineering societies, and to journals, and these papers have been selected, as stated by the editor in his preface,

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as being "most characteristic of their author in his capacity of a scientific and mathematical inquirer."

The papers range over a period of fully twenty years, and are eminently noticeable for their high scientific value, both as regards the matter treated of and the admirable method of the treatment. The papers number 37 in all, and have been grouped into three great divisions with the object of classifying kindred subjects.

In looking at the bulky volume now issued, and which, after all, contains only a selection from the various contributions of Professor Rankine, we are forcibly impressed with the mental power, energy, and perseverence, required in the author during his term of arduous pursuit of knowledge for the working out of results so profound in their speculations, and so varied in their character; and as we see his features depicted before us in the engraving, which so suitably prefaces the subject matter, we long "for the touch of the vanished hand and the sound of the voice that is still."

To his old students, and to scientific men everywhere, we need not commend the volume now published, as we are sure they will readily appreciate the memorial now offered to one so well known in the scientific world. We think, however, that the publication of such collections of papers has even a higher value, as, in after years, those who are still working in the same fields have in such volume a record of the steps trod by their predecessors, serving at once as an incentive to further investigation and pointing out what has already been accomplished. In the present volume we have also an excellent biographical sketch written by Professor Tait, which, with the editor's preface, containing a carefully prepared abstract of the paper, forms a fitting introduction to this highly important addition to our scientific literature.—*Abstract of a Review in Engineering.*

MISCELLANEOUS.

APPARATUS FOR MEASURING THE COMPARATIVE STRENGTH OF BROKEN STONES.—The French Government, after having made various experiments, have adopted an apparatus for testing the relative toughness and resistance of broken stones suited for macadamizing roads. It consists of two hollow cylinders, mounted on the same shaft, in an inclined position. Into one of these, the material selected for the basis of comparison is introduced; into the other, the material to be tested. The cylinders are slowly turned on their axis for a given time; after which they are emptied of their contents, and the respective quantities of stone reduced to powder are weighed. The ratio of these weights constitutes the coefficient of wear. The relative wears thus determined have been proved to harmonize with the results of wear in the road.

The pieces of stone selected for trial are as nearly uniform in size as is practicable—made to pass through a ring gauge, 6 centimetres, or 2.36 inches in diameter.—*Abstracts Proc. of Civ. Eng.*

TENSILE STRAIN AND ELECTRIC RESISTANCE.—Some interesting results showing the connection between the electric resistance of iron wires and their state of strain have been communicated by Mr. W. H. Johnson, B. Sc., to the Manchester Literary and Philosophical Society. The wires were tested for their resistance by means of a Wheatstone balance with reflecting galvanometer of low resistance, and for their tensile stress by an apparatus similar in principle to a steelyard weighing machine. A series of measurements were made upon different varieties of iron wire, beginning with pure iron smelted and worked throughout with charcoal, and ending with highly carbonized steel wire. The results show that charcoal iron has the least electrical resistance, or about one-half that of piano steel; and it is noticeable that the resistance regularly increases as the impurities augment. Annealed steel, which comes about midway between pure charcoal iron and piano wire in the amount of carbon it contains, is also intermediate in point of electrical resistance. Annealing considerably diminishes the electrica-resistance of puddled iron wire. The breaking strain and the resistance are also found to increase together in a fairly regular manner. Annealing is found to diminish the resistance of bright steel wire about 1 per cent., while hardening and tempering increase the resistance of the metal to the passage of the electric current. With regard to torsion, the tests show that the electrical resistance is, roughly speaking, inversely proportional to the number of twists in the length of 8 in. The importance of electric conductivity in boiler plates is pointed out by Mr. Johnson in his paper. The heat conductivity of metals is nearly proporticnate to their electric conductivity, and, as boiler plates should conduct heat well, they ought also to have a high electric conductivity.

AT a meeting of the Manchester Association of Engineers, a paper was read on the 8th inst., by W. H. Bailey, on "Recent Methods of Testing Portland Cement," in which he described a number of testing machines, and in calling attention to the enormous quantity of cement now used in hydraulic and other engineering works, showed the necessity for the most careful and frequent testing of all cement used on any work.

IN connection with the Ribble Navigation scheme, a meeting of a committee of the Preston Town Council, formed to negotiate with the Ribble Navigation Company, has been held, at which it was decided to carry on negotiations with the company; and it is expected that next session the corporation will be able to obtain an Act of Parliament for the transfer of the stock of the company and the whole undertaking to the corporation.

A TRIAL is about to be made by the Guisbrough-in-Cleveland Local Board of 100 tons of Tees slag bricks made from blast furnace slag, as metalling for the highways instead of whinstone.

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DISBURSEMENTS.		
Losses and endowments	$511,850.62	
Dividends to policy-holders	256,299.97	
Lapsed and surrendered policies, etc.	128,926.29	
Commissions, salaries, agency expenses, medical fees, etc.	186,621.12	
Taxes, legal expenses, advertising, etc	64,981.74	$1,148,679.74
Net assets, January 1st, 1881		$6,958,354.75
ASSETS.		
U.S. 5 per cent. bonds, Philadelphia and city loans, R. R. bonds, bank, and other stocks, worth	$2,941,783.50	$2,626,075.07
Mortgages, first liens on properties worth	$6,217,760.00	2,342,456.47
Premium notes, secured by policies		662,176.82
Loans on collaterals, etc.		322,119.40
Home Office, and Real estate bought to secure loans		715,796.97
Cash on hand and in Trust Companies		289,730.02
Net ledger assets as above		$6,958,354.75
Net deferred and unreported premiums	$101,444.13	
Interest due and accrued	91,674.04	
Market value of stocks, etc., over cost	315,708.43	508,826.60
Gross assets, January 1st, 1881		7,467,181.35
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Among the more extended original contributions to the later volumes may be cited new contributions to Graphical Statics—Transmission of Power by Wire Ropes—Maximum Stresses in Framed Bridges—Momentum and Vis Viva—Rapid Methods of Laying out Gearing—Transmission of Power by Compressed Air—Geographical Surveying—Mathematical Theory of Fluid Motion—Thermodynamics—Practical Theory of Voussoir Arches—Cable Making for Suspension Bridges, &c., &c.

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VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CXLVIII.—APRIL, 1881.—VOL. XXIV.

SMALL MOTIVE POWER.

By HENRY S. H. SHAW, Stud. Inst. C.E.

From Selected Papers of the Institution of Civil Engineers.

I.

THE introduction of small motors has been very extensive of late years, and is still increasing. The object of this paper is to consider, in a brief but systematic manner, the present state of the subject in this country, in order that a comparison may be formed of the relative advantages of the various agents now in use. In order to do this at all satisfactorily, an outline, at least, must be given of the modes of applying these agents for the purpose, and also the uses to which the motors themselves are put; so that, after a few preliminary definitions and remarks, the following method has been adopted:

(I.) The working agents are classified, and the causes of loss by the transformation of energy on a small scale are briefly considered.

(II.) The agents are taken in order, and the types of apparatus for applying them are dealt with and classified, and their efficiency examined.

(III.) Finally, the relative advantages of the agents are considered, with reference to the various objects for which they are applied.

It is difficult to define exactly what is meant by Small Motive Power. Whether the size of the motor, the work performed in a given time, or the object for which it is applied be taken for reference, the difficulty of assigning an exact numerical limit exists, such a limit being after all quite arbitrary; for instance, a very small engine, driven at a considerable velocity by high-pressure steam, might develop as much power as an ordinary water wheel, or a much larger engine, under different conditions; but though the term in question would include the first, it would commonly be held to exclude the two last; therefore, it will be interpreted as generally received by engineers, and will be taken to exclude locomotives and marine engines, factory and mill motors, but to embrace the large number of engines for what may be called auxiliary purposes, which are being made more and more to supersede muscular energy.

The only direct sources of power at present used for small motors are fuel and a natural head of water, fuel including every kind of substance which by chemical action, rapid or slow, develops kinetic or actual energy. No source of power can be utilized without some loss of energy, and the "efficiency" of the apparatus used is the exact numerical value of the ratio of the useful work produced by it, to the energy expended upon it, by means of the working substance or agent; this quantity is, therefore, always some fraction less than

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unity. Before the final application of energy takes place, it may undergo a number of transformations by means of various agents, two or more being often employed in the case of small motors—as, for instance, when steam power is used to produce an artificial head of water or a current of electricity, which latter may produce work; but since the resultant efficiency is the product of the fractions representing that of each intermediate piece of apparatus, the final advantage to be gained must be balanced against the loss necessarily entailed by the use of each extra agent.

The same source of power may be applied to impart energy to motors by various agents and in different ways, and in order to avoid confusion, in stating the efficiency of an agent, the source of power should also be stated; thus, taking gas as the source of power in the gas engine, and coal in the steam engine, the result of comparing these agents is very different to that obtained by taking coal as the source in both cases, and introducing as a factor in the former case the efficiency of the gas-making apparatus.

The extent to which an agent is to be used may have much to do with determining its suitability for any purpose, and may considerably modify its application; indeed, the choice of the agent may depend on very different considerations, according as it is to be used on a large or a small scale. The importance of this will be shown hereafter, and leads to the agents applicable for use with small motors being more numerous than with large ones.

Section I.

(1.) The agents may be thus classified:

Steam	. . . . .	Heat engines.
Gas	Coal . . .	
	Petroleum, &c,	
Air	Heated . .	
	Compressed	(a)
Water	Natural head	
	Artificial head	(a)
Electricity	By direct chemical action	
	By dynamo-electric machine .	(a)

The agents classed under "heat engines" form the most important portion, and will be, to a certain extent, treated of together, a heat engine being regarded simply as an apparatus by which the action of heat is caused to expand the agent, and thus to do work. Those marked (a) (a) (a) may be regarded as merely transmitters of energy, and acting in the secondary way already referred to. The respective efficiencies, of two of these, and also of steam, for this purpose, have been dealt with in a paper by Mr. Robinson,* M. Inst. C. E., from which paper it appears that water stands the highest, but the loss of head, varying inversely as the fifth power of the diameter of the transmitting pipe would cause its utility to diminish rapidly with the size of the motor. It is only recently that electricity has been much thought of for this purpose, or at any rate has been practically applied, and that agent is treated in Section II. almost entirely with reference to this object.

Before proceeding to examine the efficiencies of the agents separately, it will be well to point out the losses of different kinds attending the transformation of energy, which are common to all. These take place,

(1.) In dissipation, caused by the tendency of the agent to lose the energy imparted to it by communicating it to surrounding bodies, as, for instance, by conduction and radiation in the case of heat, and by leakage with a head of water.

(2.) In the necessary rejection of energy due to the conditions of working.

(3.) In the mechanical arrangements, in connection with which there are two principal losses, the one by friction, which is unavoidable, but may be reduced to a minimum by judicious design, the other by an improper supply of the agent, which supply may be either insufficient or excessive; in the former case the friction of the working parts absorbs an increasing proportion of the energy expended; in the latter the velocity of the motor increases, until the resistances, both useful and prejudicial, are equal to the power applied to overcome them.

As already stated, heat engines are most important among small motors, the use of gas and hot air being almost entirely applied to operations on a small scale; therefore, it seems appropriate to

* *Vide* Minutes of Proceedings Inst. C.E., vol. xlix., p. 1.

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deal in this place with the losses common to them.

The first cause of loss, viz., by conduction and radiation, is proportionately greater for small than for large engines, not only from the fact that the heated agent is generally contained and conveyed in cylindrical vessels and pipes, in which the volume varies as the square of, but the surface only directly as, the diameter, and thus the radiation is proportionately greater, but loss by leakage and imperfect lagging is also generally greater; furthermore, the loss of heat in its transference from the fuel to the agent is greater, for, as will be shown by the results of experiments, the conditions of economical combustion are harder to maintain. Both these sources of loss may, however, be considerably modified by mechanical arrangements.

The second cause of loss, from the necessary rejection of heat, is often overlooked. There is not space to examine the question as fully as it deserves, but the conclusion to be drawn is that the agent should be used between as great ranges of temperature as practicable. This is an important point in discussing their relative efficiency, and since the proportionate range for hot air is greater than for steam or gas, the efficiency of the former in this particular is the higher; but at the same time this very quality renders it less capable of developing so much power, since only small differences of pressure accompany this range, which is limited by practical considerations, such as lubrication, packing, &c. There is, however, another and a more obvious way of regarding the action of these agents so as to compare their efficiencies; the heat rejected in the waste steam or gas has to be entirely restored to the new portion of the agent, by the expenditure of fuel, while in the air engine this is partly effected by compression in the return stroke; and so, though the loss of fuel is not so great in the air engine, the high-back pressure resulting from compression makes the resultant work also not so great, and leads to the conclusion, which is verified in practice, that air engines are not so powerful as steam or gas engines, though more economical.

The higher the initial temperature of the agent the greater will be its possible efficiency, for the lower limit cannot at the best differ much from the temperature of surrounding bodies, but the upper is only limited by mechanical difficulties; and though it may be shown that it is impossible to abstract all the imparted heat in the form of work, the proportion of heat so abstracted being, in fact, never greater than one-seventh in the best steam engines of the day, yet the efforts made in this direction must be attended with success in proportion as those difficulties are overcome. In the discussion which followed the reading of Mr. Flannery's paper* on high-pressure steam boilers these difficulties seem to have formed the only ground of objection to their use. Pressures of from 300 to 500 pounds per square inch have been successfully used by Mr. Perkins, and the application of high pressures and speeds is greatly increasing for small steam engines.

The third cause of loss, viz., that from friction and imperfection of machinery, has a special interest from the high speeds now used in some small engines. It may be regarded as certain that the proportionate loss from these causes is greater on a small than on a large scale; but, again, the proportionate waste of fuel is nearly always of less consequence. From the recently issued first reports on "Friction at High Speeds," of the Institution of Mechanical Engineers, it would appear that, at any rate up to the velocities at present used, the friction seems slightly to decrease as the velocity increases.

Section II.—steam.

Steam engines are at present by far the most extensively used of small motors, some on a very small scale being made to develop considerable power.

The generation of steam on a small scale is almost entirely limited to vertical boilers—at any rate, for purposes on land—though the horizontal form, as well as sectional boilers, are also coming into more general use, the portability of the first being a strong recommendation. Figs. 1, 2 and 3 are sections of vertical boilers in common use, the general form being a cylindrical wrought-iron shell containing a furnace, also cylindrical

* *Vide* Minutes of Proceedings Inst. C.E. vol., liv. p. 123.

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and concentric with it, and fired through an opening in one side. In other particulars there is considerable difference. In Fig. 1, which, though extensively used, is deservedly falling into disfavor, the gases pass upward to the funnel through a number of vertical tubes, either a cast-iron top or an enlarged crown being necessary to allow their escape to the funnel; this latter device is shown in the figure, and also an ingenious arrangement for preventing the earlier destruction of the central tubes, by the tendency of the flames to ascend

Fig. 1.

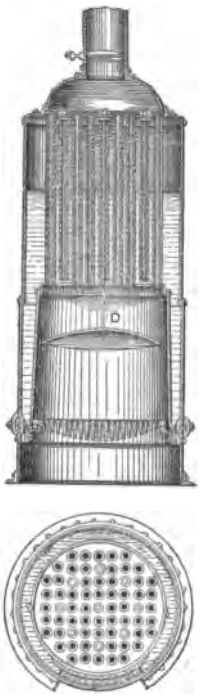
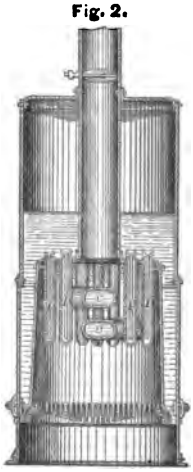


Fig. 2.



through them, which is especially the case when the fire is low. This consists of a concave wrought-iron plate (D), by whose under side the gases are reflected and are compelled to ascend round its edge, where combustion of some portion of them takes place, and the side of the furnace is acted on by the flame instead of by the current of cold air, which otherwise would be drawn up and be in contact with it. Fig. 2 is a still more common form, the gases passing up a central flue; but there are a considerable number of different devices for robbing them of their heat before this takes place; the oldest and most usual is that of the cross tubes *c*, *c*, whose section is, however, generally circular; these have the advantage of adding to the strength of the furnace; the furnace, besides being subjected to external pressure, is the vulnerable part in the, by no means uncommon, event of shortness of water. Another plan is to have pendent tubes *p*, *p*, *p*, of which the "Field" type is a good example, as it allows a complete circulation of water by separating the ascending and descending columns, by an inserted tube shown in the diagram. The success of this plan is shown from the fact that no less than 134,700 are now in use. Another good device is applied in the "Davy-Paxman" boiler (Fig. 4), in which the tubes, instead of ending in the furnace, pass down and communicate with the water in the lower part of the boiler, and so establish complete circulation, which is prevented from acting too violently by bafflers placed at their upper ends. These and various other

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arrangements, though adding to the complication of the boiler, are very desirable if effective in action, for the loss of heat in them, which experiments indicate, is thereby much diminished. Thus the boiler of Latham and Bradley, 10 feet high and 4 feet in diameter, has 132 square feet of heating surface. Fig. 3 is an excellent design known as the "Talbot," which presents considerable heating surface; the furnace is of cast iron, which in a recent modification is lined with firebrick, and the ash box acts as a water heater. These boilers have at *d*. Another form of sectional boiler may be briefly described as a square box of tubes, which run from side to side in two directions, and through which the flames are made to pass successfully. Yet another form, which is used in America, consists of a series of cast-iron spheres with necks, which are faced, and so connection is made by means of long bolts. The advantages of sectional boilers are summarized in the paper of Mr. Flannery,* where there is also a quotation from the third report of the Admiralty on the subject. There is a large

Fig. 3.

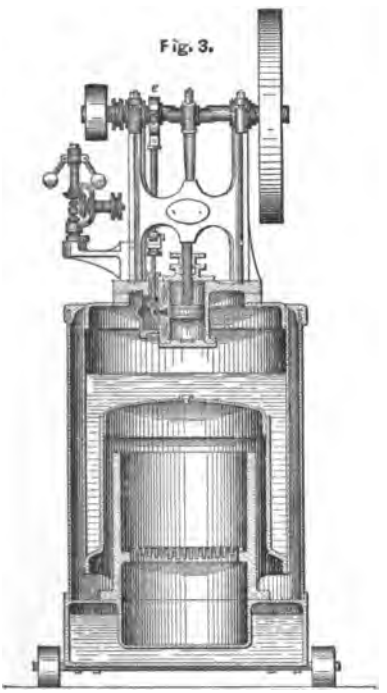
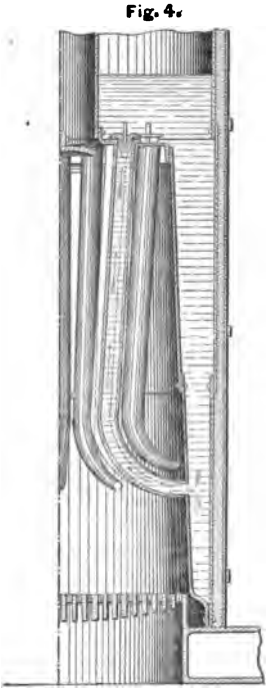


Fig. 4.



given good results in practice, and the advantage of a non-tubulous boiler with large heating surface is realized by those who have experienced the cost and trouble which tubes often entail. Fig. 5 is a view of an ordinary sectional boiler, and it will be seen that the amount of heating surface exposed must cause it to be a rapid steam generator. The arrangement *a*, *a*, *a* of firebrick and the iron plates *b*, *b*, *b* divert the flames, and compel them to pass well round the tubes, after which they escape by the flue *c*. A portion of the steam space is shown

number of inventions of both vertical and sectional boilers, but the foregoing examples are typical of the forms generally used. A small vertical boiler commonly has the engine attached to it, and forms its support; this may be effected by bolting the engine either to its side, or by means of a cast-iron bedplate or a wrought-iron ring securing it upon its top. Portability is thus secured, and the evils arising from alternate expansion and contraction of the boiler,

* *Vide* Minutes of Proceedings Inst. C.E., vol. liv. p. 128.

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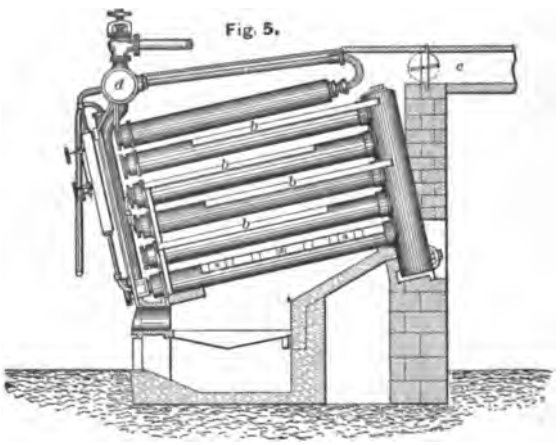
which would be felt in a large engine, are not in this case appreciable, chiefly because when used on a small scale the engine is only connected with a fixed external object by a belt or bearing at a little distance from it; but it has been remarked that with small marine engines, where the case is different, the objection is considerable. One excellent example of the latter method is afforded by the design shown in Fig. 3, in which the cylinder is let into the boiler, and, besides the benefit of short steam connections, a perfect steam jacket is formed.

The efficiency of small boilers is a most important thing to consider, and, so largely are they at present in use in



in conjunction with small engines, that it would be impossible to form a satisfactory comparison between small motors without some reliable data on the subject. Now the paper of Mr. Flannery indicates a high efficiency for sectional boilers, but these are not used to anything like the same extent as the vertical form; and on turning to different sources for information, the author was unable to obtain independent results. For instance, in the comprehensive manual of Mr. D. K. Clark,† M. Inst. C.E., although boilers of marine, locomotive, stationary, and portable engines are fully treated, yet the class in question is not mentioned; and the ratio of heating surface to grate area and other conditions

† A manual of "Rules, Tables, and Data for Mechanical Engineers." Blackie and Son.

are so different in these latter, that no comparison can fairly be drawn. This information being required, and also data concerning the working of small steam engines of the ordinary type, through the kindness of Mr. Fry, Managing Director of the Bristol Wagon Works, and of Mr. Arrowsmith, Steam Printing Works, Bristol, two series of experiments were made upon a 2-HP. vertical engine and boiler, manufactured by Dodman, of King's Lynn, belonging to the former, and a 4-HP. horizontal engine called the Soho, and a vertical boiler made by Tangye, of Birmingham, belonging to the latter. The data now given will refer only to the boilers, that of the engines being introduced hereafter. During the two days' trial of the former, which will be called No. 1, and one day's trial of the latter, No. 2, the difficulty was experienced of keeping uniform the quantity of water and the pressure of steam; but during a run of three hours on No. 1, and of four hours with No. 2, by careful stoking and attention, and by taking observations every quarter of an hour—of revolutions, pressure of steam, and supply of feeding water—a close approximation to regularity was obtained. Both the dynamometer and the indicator were used, and the quantity of feed water and coals carefully weighed, and, as will be shown in No. 2, the volumes of steam used agreed fairly well with the volume of the cylinder and ports obtained by actu-

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ally filling these spaces with water afterwards, so that little, if any, priming could have taken place in No. 2, while in No. 1 the difference must not be overlooked, and the boiler efficiency in this case can only be approximate. No. 1 was of the form shown in Fig. 1, and was well lagged all over; No. 2 was of the form represented in Fig. 2, but was deficient in heating surface, having no pendent tubes and but one cross tube, circular in section.

Table of Results of Experiments on Small Vertical Boilers.

Boiler.	Height.	External diameter.	Number of tubes.	Diameter of tubes.	Length of tube.	Diameter of furnace.	Area of grate in sq. ft.	Height of furnace in feet.	Heating surface in sq. feet.	Ratio of heating surface to grate area.	Mean pressure on boiler in lbs. per square inch.	Water evaporated per hour in pounds.	Coal used in lbs.	Evaporation in lbs. of water per lb. of coal from 100° F.	Efficiency of boiler.
	Ft. in.	Ft. in.		in.	Ft. in.			Ft. in.							
No. 1.	4 6	2 6	7	2¼	2 2	..	1¾	1 9½	21.2	12.0	51.5	121	36¾	3.3	0.26
No. 2.	5 4	2 6	1	8	2 0	..	3¼	3 0	26.8	8.54	32.0	170	34½	4.9	0.39

The feed water was warmed to about 100° Fahrenheit. The coal used with No. 1 was Parkfield; an analysis, with which the author was kindly furnished by Mr. Handal Cossham, shows 82 per cent. of carbon, 5.6 per cent. of hydrogen, and 6.1 per cent. of oxygen, and has a heating power of 14.3 pounds of water, at 212° Fahrenheit, converted into steam; so that, theoretically, the evaporation should have been from 100° Fahrenheit, about 12.5, instead of 3.3 ∴ Efficiency $=\frac{3.3}{12.5}=0.26$. With No. 2 the evaporation should have been about the same, making its efficiency $=0.39$. Thus, although the ratio of heating surface of No. 2 was considerably less than No. 1, the evaporative power was greater, which seems only to be accounted for by the fact that most of the heating surface of the latter was vertical. If the average evaporative power of large boilers from 100° Farhenheit for this kind of coal be taken at 0.65, it is seen how much inferior these small boilers are to larger ones, although from what has been said it is seen that these boilers are being superseded by more efficient ones, with larger heating surface, as Latham's and Bradley's, which, though little larger than No. 2, has five times as much heating surface, and the field, of which there are 1,380 in use; but the introduction of more heating surface by tubes, &c., offers a larger surface for corrosion and leakage, and therefore involves more repairs; and the general conclusion is that the necessity for small boilers is the weak point in the use of steam on a small scale.

There are four ways of using steam on a small scale, which seem to lead to the following classification:

(1.) Single-acting engines using high pressures and speeds.

(2.) Double-acting engines using moderate pressures and speeds.

(3.) Rotary engines.

(4.) Apparatus for causing the pressure or impulse of steam on fluid surfaces to directly raise or force that fluid.

The first three are always non-condensing engines; the last kind can hardly be called engines, being apparatus of the injector or pulsometer type; but as they are used principally as a substitute for other kinds of steam pumps, or manual operations, they must certainly be considered as included by the term Small Motive Power. Thus it may be said that all small steam engines are non-condensing. This is obviously because the gain due to the partial absence of back pressure, which condensation secures, would not be sufficient to compensate for the increased complication and

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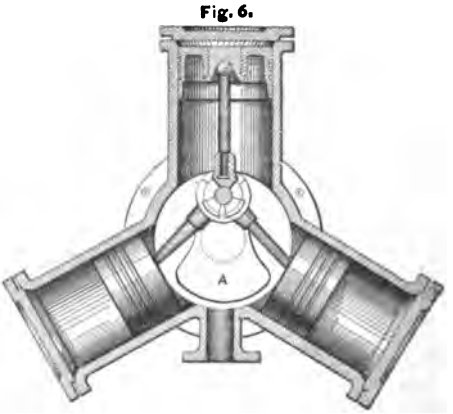
first cost which would at the same time be entailed; while the difficulty of maintaining a good vacuum increases, as also does the proportionate work done by the air pump, as the size of the engine diminishes. This fact has an important bearing on the pressure used; for it must be remembered that the effective pressure is the difference between the forward and the back pressure, the latter being, in the above cases, nearly constant. Low forward pressures must be very wasteful, the limiting case being when the forward and back pressures are equal, for then the whole imparted heat would, in a non-condensing engine, be absolutely thrown away.

SINGLE-ACTING ENGINE.

(1.) These engines have been largely introduced for high speeds, so as to save the necessity of intermediate gearing, and to develop considerable power with a small motor. They almost invariably have multiple cylinders, generally three, as in the well-known Brotherhood example, and in those of Watt, Wigrell and Hasley, and Willans; while Vosper's engine has four. The steam only acts on one side of the piston. The great advantage of this is, that there is no shock from the wearing of the connecting-rod ends, or "backlash," as it is called. This is most important, at the almost incredible velocities at which some of these little motors work—many by the first-mentioned maker working at 1,400, and some even at 1,600 to 1,800 revolutions per minute. Moreover, the piston rod and guide blocks are dispensed with, and parallel motion is secured by having a deep piston, to which the connecting rod is attached, and thus compactness is obtained; the absence also of eccentrics and eccentric rods renders the working parts few in number, while the use of the flywheel is entirely obviated. Of the numerous forms, that of Brotherhood has by far the most extensive application; and it may be said that the one exhibited by the inventor at the Vienna Exhibition, in 1873, which gained a silver medal, was the first of the class of which several hundreds have been made by him alone, and a large number by other inventors, who have since worked in this direction. It is thus seen that there is a movement in favor of a system by which considerable power is obtained from a small motor. Of this type a brief description of the Brotherhood engine only will be given, as engravings and descriptions of the others are to be found in comparatively recent numbers of various engineering journals.

Fig. 6 is a section through the three cylinders of a Brotherhood engine; the crank being balanced by a counter weight A, and the three connecting-rod ends merely butting against the crank pin, to which they are held by two steel rings. The valve is a rotary one, and its action is shown in Fig. 7, which is a longitudinal section. The steam is being ad-

Fig. 6.



mitted to the top of the piston by the port J, the opening in the valve putting it in communication with the steam chamber G. The exhaust is made by the passage N′ being placed in communication with the annular space in which the crank works, and finally escapes through the exhaust pipe, Q, placed at the bottom of this chamber. The steam pressure was about 70 lbs. per square inch, with 250 revolutions per minute. The compression, which commences rather before half-stroke, can scarcely be a source of loss, as it allows the entering steam to rise to the full pressure at once, and certainly results "in the complete suppression of all species of shock." This, in a single-acting engine, with no arrangement for tightening the connecting-rod bearings, is a desideratum. The wire-drawing, obvious from the diagram, is the result of the circular valve, which, advantageous as it is for many reasons,

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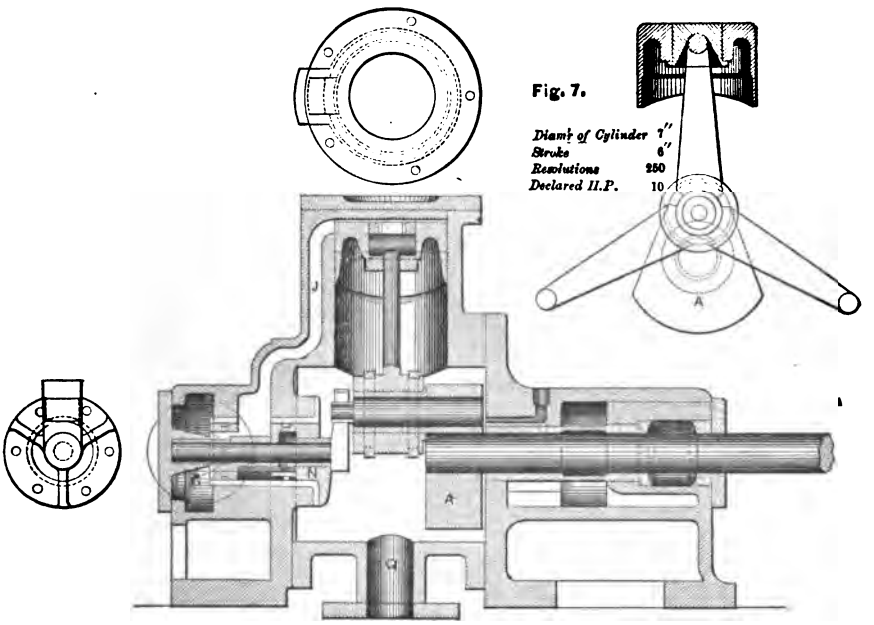
is not moving at its greatest speed as with the ordinary slide valve, when the engine is near its dead centers. Fig. 8 shows the period of its action. The efficiency of the machine itself, that is the ratio of the indicated work to that obtained at the brake, is 75 per cent. The developed power was 10 HP. It is to be regretted that no determinations of fuel and steam used were taken. But although it has been asserted that these engines are wasteful of steam—and certainly the length of steam passage must entail a loss—yet on some trials made by

DOUBLE-ACTING STEAM ENGINE.

(2.) The second class of small engines, viz., those which are double acting, and generally work with a single short D-slide-valve, are at present by far the most common, and a section of one of this type is shown (Fig. 3). Now, although the forming is made to take every concievable shape, and they are made to work in every position, and have slight differences of detail, yet the principle of action is the same, and is so well known as to need no explanation. The



BROTHERHOOD'S 3 CYLINDER ENGINE

the Royal Engineers, in which these engines were used to drive Gramme machines, the consumption of steam was 41.1 lbs. per hour per HP.,* revolutions 500 per minute, pressure of steam 80 lbs. per square inch, about 13 HP. being developed. This agrees with the consumption of steam obtained by officers of the French navy, which, the inventor states, was 40 lbs., and is equivalent to an expenditure of from 4.5 to 5 lbs. of coal with a good boiler, or 8 lbs. with one of the type already examined.

* "Engineering," vol. xxiii., p. 320.

point of cut-off of the steam is from $\frac{5}{8}$ to $\frac{3}{4}$ of the stroke, the corresponding grade of expansion being from $1\frac{3}{5}$ to $1\frac{1}{3}$, and more expansion than this cannot be economically effected with a single valve. The two engines before referred to cut off steam at about the latter point. The details of the experiment were as follow: Both the indicator and the dynamometer were used, the latter being of the ordinary form, that is Prony's dynamometer lined with blocks of elm, embracing pullies respectively 2 feet 7 inches and 3 feet in diameter in the two cases. No. 1 was a vertical engine, and

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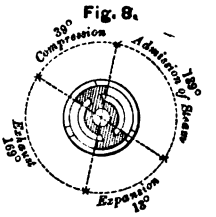
was bolted to the boiler. No. 2 was horizontal, and rested on a foundation of brickwork and stone. The number of revolutions varied to some extent, but were taken every quarter of an hour.

Fig. 8.



The experiments would perhaps have been more satisfactory if a speed counter had been applied, since with a brake on a small engine the action cannot be kept perfectly regular, and the governors were purposely disconnected. However, the following Table is without doubt a near approximation to the truth:

that the final efficiency of the whole is only about 0.19 in No. 1, and 0.3 in No. 2, that is theoretically possible for an engine using steam at those pressures and with those grades of expansion, but employing a condenser and having a boiler of 0.7 efficiency.

An ingenious kind of steam engine is used in the engineering laboratory, University College, London, invented by Mr. H. Davey, M. Inst. C.E., of Leeds, which is the only one of its class yet made. A small quantity of water is injected at each stroke into a coil of pipe heated by a furnace, and is at once converted into steam, and so drives the engine, which is single-acting, about ¾ HP. being developed. Improvements are being made in the design, and Professor Kennedy, M. Inst. C.E., thinks the invention a promising one.

Small oscillating steam engines have been used, but the admission and release

TABLE OF DATA FROM ENGINE TRIALS.

Engine.	Diameter of cylinder.	Stroke.	Number of revolutions per minute.	Average pressure in boiler, by gauge, in lbs. per sq. in.	Mean pressure in cylinder by indicator, in lbs. per sq. in.	Indicated HP.	Developed HP. (brake).	Efficiency of machinery D.H.P. = I.H.P.	Steam in lbs. per hour per I.H.P. by weighing feed-water.	Steam in lbs. by calculation.	Coal in lbs. per hour per HP.	Efficiency of engine supposing efficiency of boiler=0.7.	Real final efficiency of boiler and engine.
	Ins	Ins											
No. (1) 2 HP. nominal.	4½	7	180	51.5	39.0	2.57	2.011	0.78	47.2	42.32	14.3	0.035	0.013
No. (2) 4 HP. nominal.	6½	7½	133	32.0	22.3	3.75	3.040	0.80	45.3	44.0	9.2	0.039	0.022

These results show that in this class of engine, at any rate, the consumption of fuel is at least from four to seven times greater than in the best kind of large engines, and that it is therefore beside the question to quote the performance of large engines when comparing the working cost of small motors. In connection with the indicated power of No. 2, which is less than the nominal, it is only fair to state that the engine often works with about 40 lbs. pressure and 180 revolutions, which would cause it to indicate more than 6 HP. A similar remark applies to No. 1. Again, it is well to note of steam, to be effected economically, require rather complicated valve gearing.

There is another class of double-acting steam engines which are not rotative, and since merely reciprocating action is obtained, the slide-valve has to be driven by some arrangement other than an eccentric. Such engines are often used as donkey pumps and often as steam rock-borers. An instance of the former is the "Special Steam Pump;" a description of its action is to be found in the pamphlets of Thurston or Evers on the steam engine.

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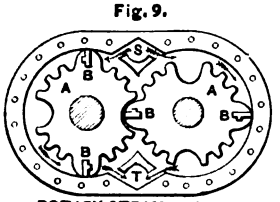
ROTARY ENGINES.

(3.) It was stated in "Engineering," six years ago, that "most mechanical engineers now-a-days have a deeply-rooted antipathy to rotary engines." Nor has the appearance of any successful patent between that time and this caused an alteration in opinion. Rotary engines are understood to be those which obtain circular motion directly by the action of steam upon some revolving piece, and so avoid the necessity for the conversion of reciprocating into circular motion. It is not to be wondered at that a large number of ingenious attempts should have been made to thus obviate the use of the crank and the connecting rod For instance, thirty years ago, one of the form known as a "disc" engine, was for some years years used to drive the printing machinery in "The Times" office, and is described by Rankine;* but although according to that author "the number of rotatory engines which have been patented in Britain alone is certainly upwards of two hundred," yet "very few have been brought into practical operation, and those to a limited extent only; for their friction and liability to wear have been found to be greater than those of ordinary engines, and they have no advantage except compactness." There is, however, one purpose to which they have recently been applied with some success, viz., to fire-engines, where economy of fuel, which the difficulty of keeping the revolving portion steam-tight renders impossible, is not the chief point, and where the use is only occasional, and so the wear not of the first importance. Fig. 9 shows a simple

Fig. 9.



ROTARY STEAM ENGINE

form which is used for this purpose. Here the steam entering at S drives round the discs A, A, in opposite directions, and, finally escaping at T, A, A, give motion to two similar discs, which act as the pump by a similar action, and so great compactness is obtained. The method of packing is ingenious and effective, and is formed by the metal pieces B, B, being pressed outwardly by springs, their centrifugal force acting with a similar effect. Behrens' engine is similar in action, and is much used in America as a pump.

STEAM ACTION ON FLUID SURFACES.

(4.) Two kinds of action are used. The first, Mr. Bramwell, F.R.S., M. Inst. C.E., has said, is expressed by one word "Concentration," and may be said to act by impulse, to which belong the Giffard Injector and the Inspirator. The second uses the principle of the Savery engine and acts chiefly by pressure, of which the Pulsometer and Pulsator are types. As before stated, this class of apparatus is employed for pumping purposes, and this may be said to be its exclusive duty; its use in this direction is increasing, and whenever there is a supply of steam the simplicity of action and remarkably small weight and size of the whole machine are great recommendations.

The theory of the action of injectors is now well known, so that it will not be necessary to describe any one of the numerous forms in use, although a reference to Hancock's inspirator may be made. This little instrument is becoming very popular, as it admits of accurate adjustment, after which little attention is required; while the weight of one capable of feeding a 48-HP. boiler is only 6 lbs. The undoubted function of all injectors is the foregoing, viz., the feeding of boilers, and they are universally applied to locomotives for this purpose.

The second kind are really steam vacuum pumps. The "Pulsometer" is a very successful example. The action is automatic and alternative, and the arrangement is, in fact, a self-acting Savery engine. As with the Savery engine, however, the consumption of fuel is considerable. Trials were made at the Cincinnati Exhibition in 1875, quoted by Mr. D. K. Clark,* and at the Friedrich Lead Mine, Upper Silesia, recorded in the

* "A Manual of the Steam Engine and other prime movers," p. 504.

* "A Manual of Rules, Tables," &c., p, 969.

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Abstracts of Foreign Papers.* In the former case, 53.1 lbs. and 43.4 lbs. of coal per hour per HP. for water actually raised were expended on two respective trials; in the latter 52.4 lbs. of slack were used for the same amount of work; but in the latter trial a "Tangye" pump consumed 40.5 lbs. for the same duty. The conclusions drawn from this trial, and other data obtained by experience, were that the total outlay for stores and repairs with pulsometer was 1.68d. per hour per HP., that for the piston pump being 1.44d. The great recommendation of the former, however, is its portability, as it is as well able to work when slung by a chain as in any other way; also it will, in the words of the advertisement, "pump almost anything," including tar, sewage, chemical liquids, and even liquid cement, and is one-half cheaper in first cost than an ordinary pump of equal power; thus there is evident reason for the extensive sale which it enjoys. A recent modification, under the name of the "Hydrotrophe," is being employed to feed boilers, and both this and the injector must be economical, the surplus heat imparted to the water being returned to the boiler.

GAS.

Gas is a convenient source of power; and in towns, where it is already supplied almost to every building for purposes of illumination, it is at once obtainable in any moderate quantity. Moreover, the principle of adopting a large centre of supply, which is employed in the case of gas, is, on scientific grounds, truly economical, for that substance is supplied in the state of fuel, and involves no more loss in its transmission than would occur in the transference of any other fuel. But in spite of many attempts to use it for small motors, it has only recently been much adopted. Air is used in a peculiar way in the gas engine, and it is only in a similar way that gas can be profitably employed, viz., as the working agent, at the same time as the source of power; for the calorific power of gas, taken in conjunction with its present cost, at once puts out of the question any idea of using it as a direct substitute for coal.

The original method of using gas in this way was to admit it to the cylinder of the engine, together with air in such proportions as to form an explosive mixture, which was ignited, and work obtained by the consequent expansion. Lenoir's engine, which was one of the first, resembled an ordinary horizontal engine, effecting the ignition by an electric spark; but the difficulty of utilizing this sudden effect was a cause of considerable loss, and it is stated by a German writer on the subject* that 3 cubic metres (about 106 cubic feet) of ordinary coal gas are required per hour per HP. for a small sized engine. This corresponds to the figures quoted by Mr. D. K. Clark† from the experiments of M. Tresca, two successive trials of this engine, giving 112 and 97 cubic feet respectively, the mean of which is 104½ cubic feet per hour per HP. at the brake, being an efficiency of little more than 4 per cent. Though this engine had an extensive sale in Europe, it was to a great extent superseded by the Otto and Langen motor. In this the sudden expansion of the gas was allowed to raise a piston against the pressure of the atmosphere alone, which pressure, upon the cooling of the heated gas in the cylinder hastened by a water jacket, drove down the piston and so performed work, the piston-rod being a rack which geared with a pinion on the horizontal shaft. This engine is a regular and efficient motor, and its consumption of from 22 to 30 cubic feet of gas per hour per HP. is vastly superior to the Lenoir engine, and is even less than in some engines which have superseded it. One engine, which has been at work for ten years in Bristol is in good condition, and has cost during that period very little for repairs; but its noise in working is much against its general adoption. Again, it is necessarily a vertical engine, by no means so popular as the horizontal form, and is anthing but compact. Thus when the new engine of Otto was introduced into this country by the same manufacturers, Messrs. Crossley Brothers, of Manchester, which was at once compact, economical, and above all, silent, they almost at once ceased to make the Otto and

* *Vide* Minutes of Proceedings Inst, C.E., vol. lvi., page 371.

*"Klein-Kraft-Maschinen," p. 27. Von Peter Hell, Braunschweig.

†"A Manual of Rules, Tables," &c., p. 921.

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Langen, and have already sold, since 1877, upwards of eight hundred of what are known as the Otto Silent Eugine, more than two thousand being the number sold in Great Britain and on the Continent. The principle of action employed, as indeed of nearly all the many kinds since patented, is intended to meet the difficulty of utilizing the energy of the gas consequent upon the sudden explosion in former engines. The method of doing this is best stated in the words of the specification of the English Patent, No. 2,081, 1876: "A combustible mixture of gas or vapor and air is introduced into the cylinders, together with air or other gas that may or may not support combustion in such a manner that the particles of the combustible mixture are more or less dispersed in an isolated condition in the air or other gas, so that on ignition, instead of an explosion ensuing, the flame will be communicated gradually from one combustible particle to another, thereby effecting a gradual development of heat and a corresponding gradual expansion of the gases, which will enable the motive power so produced to be utilized in the most effective manner." Fig. 10, is a sectional plan taken from the same source, and is similar to the engine now manufactured, except that a single instead of a double crank is used. "The cylinder is constructed of greater length than the stroke of the piston, so that there is a space beyond the latter when it is at end stroke. Assuming this space to be filled with a portion of the gaseous products of combustion resulting from the last stroke, the piston, in performing one part of its stroke, draws in atmospheric air, after which it will draw in combustible mixture during the remainder of the stroke." These three strata of gases are compressed in the return stroke, and ignited, when the principle above quoted comes into operation; and the next forward stroke does useful work, the fourth, or next return stroke, expelling the product of combustion. The slide valve is made alternative in its action, by being driven through a bevel wheel on the main shaft of half the diameter of that on the slide-valve rod. The mixture used is 1 part of gas to 16 parts neutral; the latter being made of air and products of combustion in the proportion of 5 to 3. Some recent inventors adopt the main principle involved, but they employ a separate compression cylinder, and by advertising a combustion at each revolution, seem to imply the alternate action to be objectionable; and it must be confessed that the Otto engine is not perfectly regular in its action with a light load, combustion taking place perhaps only once in five or six revolutions. At the same time, with a proper load and a moderately heavy flywheel, this is hardly appreciable, and is of undoubted benefit to the cylinder, which, being also single-acting, is thereby only heated once in four strokes. One such engine has been running day and night at the Hinckley Gas Works for fourteen months, this being equivalent to three years' ordinary work, without needing any repairs, which, notwithstanding the water-jacket surrounding

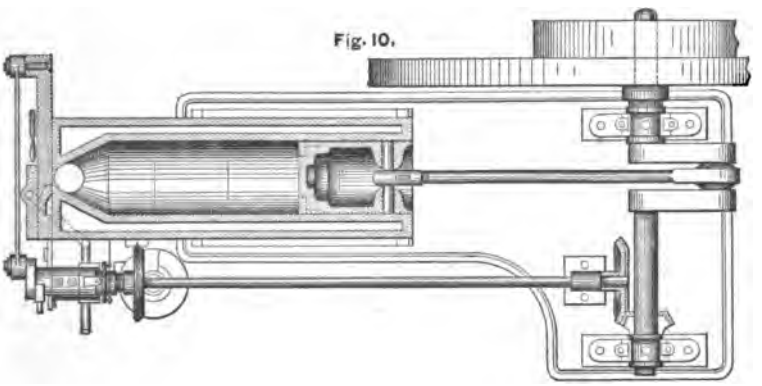
Fig. 10.

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these cylinders, is a satisfactory results and is contrary to many predictions concerning it. Such a result may possibly not attend those burning gas at every revolution.

The latest trials of the amount of gas used are, according to Mr. Crossley, 24 cubic feet per hour per HP. for the 1 or ½ HP. engines, and 18 cubic feet for the 16 HP. engines.

Another engine, the Eclipse, of Messrs. Simon Beechey & Co., of Nottingham, with a separate compression cylinder, has a novel feature, in the use of steam, which is generated by the heat abstracted from the cylinder in order to keep it moderately cool. This steam is used in the cylinder not only to assist the action of the expanding gas—which it certainly does, being capable of driving the engine for several minutes after the supply of gas is turned off,—but it also acts as a lubricant, by which it is claimed that a great saving in oil and tallow is effected. Its action is fully described, and drawings are given in the "Engineer," 1879,* and the "Textile Manufacturer," May, 1879. In the former it is stated that in a trial of one, the working cylinder, which was 8 inches in diameter, with 16 inches stroke, indicated 6.03 HP., and the compressing cylinder, which was 7 inches in diameter, with 10 inches stroke, indicated 1.87, leaving 4.16 HP. as the net indicated HP. of the engine. The consumption of gas was from 22 to 26 cubic feet per HP. per hour.

The objection to the foregoing type of engines is that they have to be started by hand and turned through a revolution or two; although the makers of the latter engine are said to have obviated the necessity for this by an invention. With very small powers this objection is not felt, nor is it with a recent novelty, the Bisschop. This little motor, which is made from 1-man power upward, has had a sale of three hundred during the first nine months since its introduction: the consumption of gas is greater in proportion than in other larger gas engines, but its first cost is very small, and being advertised to work for ½*d.* per hour, although by no means a silent engine, it has decidedly met a long-felt want.

* *Vide* vol. xlvii., p. 3.

The theory of gas engines is yet imperfect; but some things are certain with regard to them, and one is, that the absence of a boiler in connection with them gives a great advantage over the steam engine. The absence of risk either from explosion or conflagration is another strong point; while the scientific application of production on a large scale, in the form of the gas used, is perhaps the strongest of all, in leading to the conclusion that their present popularity is likely to last, gas engines being a step in the right direction.

HYDRO-CARBON MOTORS.

Another class of engines must be alluded to, although not much in use in this country, viz., hydro-carbon motors. In America, where petroleum is abundant, successful attempts have been made thus to apply it, and its use is now rapidly extending. The principle of action is much the same as with a gas engine. In the Brayton motor, described in "Engineering,"* a jet of air is forced into fibrous material soaked in petroleum, and this substance is deposited on the meshes of wire gauge, from which it is evaporated. The vapor forms with the supply of air a combustible mixture, which is, as in the Otto silent engine, not explosive, but admits of gradual combustion, with the attendant advantages. In Germany the Hock motor is commonly adopted; its appearance is similar to an ordinary horizontal engine, and the German writer already quoted† describes it as sucking in a small quantity of the fluid to about ⅓ of its stroke, and also a certain quantity of air, when ignition and gradual expansion take place through the remaining ⅔. Brayton's motor, in the article referred to, is said to use a gallon of crude petroleum per HP. per day of twelve hours, this amount being slightly exceeded in engines of less than 3 HP. The Hock engine is stated to use what is equivalent to 2.75 pounds of naphtha per hour per HP., at the cost of about 3*d.* per hour, a 1-HP. engine being in first cost about £50. Petroleum motors may be advantageously used in place of gas engines where a

* "Engineering" vol. xxiii., p. 127.
† "Klein-Kraft-Maschinen," p. 33.

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supply of gas cannot be obtained, and where petroleum is abundant, but this leads to the conclusion that, although in America and in Germany their use will probably increase, in this country, at present, it is not likely to do so.

PNEUMATIC PROPELLER FOR RAILWAYS.

By L. GONIN.

From "Abstracts" of the Institution of Civil Engineers.

THE author describes a new form of valve and piston carriage for the tube of a pneumatic railway. It is proposed to use air compressed to 6 atmospheres, and to apply the system, on grounds of economy and safety, to lines having heavy gradients and but little level track. The tube is of cast iron provided with numerous exterior stiffening ribs, and fixed upon cross sleepers between the ordinary rails, the latter being laid on longitudinal resting on the transverse sleepers. The slot in the upper part of the tube is beveled on its interior edges, thus forming a seating for the continuous valve. The valve, made of greased leather, wrapped round a wooden body and having an iron band above and below, is in the form of a truncated wedge with the narrow end upwards, so that the pressure of the air within the tube may press the valve tightly into the wedge-formed sides of the longitudinal slot. The valve, when not pressed upwards by the air, hangs within the tube from a continuous flat band of iron, wide enough to overlap the slot in the tube, and to rest on the edges of the slot. Both iron band and valve are sufficiently flexible, their connection at a distance of some inches by bolts not materially affecting this quality. When the valve is in mid-position, vertically, so that the valve is clear below its seat, and the iron band is clear above the upper edge of the slot, there is room on each side of the connecting bolts for the passage of a double coulter piece, connecting the piston in the tube with the carriage above, which is driven by it. The part of the valve at and behind the piston is kept up in its highest position by the compressed air, while the part ahead of the piston falls to its lowest position. The carriage driven by the piston carries in front a small wheel which runs upon and presses the iron band down, and thus regulates its position for the passage of the coulter. The coulter may be either attached to a large vehicle or, by the author's preference, to a small chariot running on separate rails on the top of the tube, and drawing its load by chain connection, or the load may be pushed by a buffer. The corresponding buffer, which would be carried by the engines on a line employing the compressed air system for helping trains up heavy gradients, is made to rise and fall so as to clear the chariot until beyond it. It is then dropped, and the chariot brought into work. The arrangement of valve described differs entirely from those of Clegg and Samuda, employedon the atmospheric and pneumatic railways,and it affords a tight joint, while it has not to be raised by, nor is it exposed to any wear by, the coulter. The latter is moreover double, one-half passing into the tube on either side of the valve, the strains upon it being thus of a simple order.

As the quantity of power required for compressing air does not increase with the increase of pressure, but in proportion to the logarithm of the pressures, the author proposes pressure as high as from 6 to 10 atmospheres, so that the air may be employed expansively, the full pressure being used for starting and traveling the greater part of the journey on inclines; the air would then be cut off, and the remainder of the journey performed by expansion. An experimental length of tube, 10 inches in diameter and 131 feet in length, has been constructed, the results of experiments with which are given.

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NOTE ON THE PRESENT SYSTEM OF PERMANENT WAY ON THE SIX CHIEF RAILWAYS OF FRANCE.—By E. Lecocq.—Steel rails are now almost exclusively used, but the section and weight of rail differ widely. The Eastern, the Northern, and the Paris, Lyons, and Mediterranean companies use only the flange rail; but the Orleans, the Midland and Western use also the old double-headed rail. The flange rail used on the Northern, and on recent extensions of the Western lines, weighs 60½ lbs. per yard, and is noticeable chiefly for the small width of the base (3 1/16 inches), as compared with the height (5 inches bare). This type of rail was introduced on the Northern some six years ago, so presumably it has proved satisfactory.

The Eastern company uses also a 60½ lbs. rail, but the height is reduced to 4¾ inches, and the base increased to nearly 4 inches.

The Lyons company employs two sections, the heavier one weighing 77½ lbs. per yard, and measuring 5⅛ inches high, by 5⅛ inches wide, and the lighter one weighing 66½ lbs. per yard, and measuring 5 inches by 4 inches base.

The width of head as a rule is 2¼ inches, and the length of rail about 26 feet. With the exception of some practically obsolete types of "pear headed" rail, the angle for fishing is ½ to 1, and the thickness of web in most instances is rather less than ½ inch.

A diagram and table, illustrating the arrangement of the sleepers and joints, lead to the following conclusions:

1. Suspended joints are adopted by five out of the six companies, the Northern alone putting a sleeper under the joint.

2. The spacing of the sleepers next the joint is always about 2 feet from center to center.

3. On the Lyons and on the Western railways, the sleepers next to those at the joint are spaced a less distance apart than the remainder. This also is necessarily the case on the Eastern and Northern lines, because the fish-joints are not opposite each other, but lap about 2 feet.

4. Expedients to prevent the longitudinal movement of the rails are adopted by five out of the six companies.

5. Finally, it appears that, with the exception of the Lyons company, the weight of the flange rail track is about 323 lbs. per yard, while the double-headed way attains a mean weight of 403 lbs. per yard. This excess of 80 lbs. per yard is considered by the author to be eminently favorable to stability, especially with the heavy loading and great speed of modern trains.

The following are matters of details not shown in the table, but considered worthy of notice:

1. Four bolts are now invariably used for fishing, instead of three, as was commonly the case some time ago.

2. Grooved fishes are used by three of the companies; the others use shoulder bolts.

3. Wood screws are exclusively used for fastening the rails and chairs by the Eastern, Northern, and Western companies, and by the Lyons company for their lighter rail. Trenails are still used for fastening the chairs by the Southern and Orleans companies. The Lyons company fasten their heavy rail with a fang bolt on the outside, and a trenail on the inside of the 5⅛ inches flange.—*Revue générale des Chemins de fer.*

IT is well known that ordinary letter paper if rubbed acquires electric properties. M. Wideman, has, however, says the *Electrician*, found that if one takes Swedish filter paper, or this paper laid between pieces of letter paper, and subjects it to the following treatment, it displays strong electric properties, and sparks several centimeters in length can be obtained: The paper should be plunged into a mixture of nitric acid and sulphuric acid of equal volume. The paper thus pyroxilized is then washed in plenty of water and dried. Then rub quickly, having stretched it on a waxed cloth, in order to give it electric properties. Nearly every experiment with static electricity can be accomplished with the paper.

THE people of Portage La Prairie have consented to make a branch line to the Canada Pacific Railway of five miles in length, if the Government would furnish rails and rolling stock, and to hand it over to the Government on completion.

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NOTES ON RAILROADING.

By J. A. L. WADDELL, C. E.

From the Papers of the Pi Eta Society of Rensselaer Polytechnic Institute.

THE subject with which I beg leave to occupy your attention this evening and, if such be your pleasure, at some future meetings also, is that of Railroading. It is not my intention to cover in these notes the whole subject of Railroad Engineering, but simply to convey to you, who are soon to become engineers, an idea of what *practical* railroading really is, in order that you may not feel at a loss how to proceed should you, at any time, be called upon to take charge of a survey or construction party. The facts here stated have been obtained principally from personal observation and experience, and I have avoided as much as possible dealing with those parts of the subject that are treated in standard works; nevertheless for the purpose of making what I have written clear and continuous, I have had to touch lightly upon some of them. In dealing with such a technical subject as this one, it is impossible to avoid repetition of certain words and expressions, so you will please make all due allowance for the phraseology of what I am about to read to you, and do not expect to hear the flowing language and easy style which one might employ in dealing with a literary subject. Especial reference is made to "bush work," for by far the larger portion of American railroading partakes of that character; besides, nearly all the difficulties met with in running a line through a well-settled country or prairie land are encountered in the bush, in addition to many others of an entirely different nature. The building of a line of road may be divided into four distinct steps, which will be treated separately; they are Exploration, Preliminary, Location and Construction.

EXPLORATION.

The data usually given to the engineer who makes the exploratory survey, are the *terminii* of the line, various points through which it is to pass, and the general character of the road. The latter is determined by the principal object for which the road is to be built, whether for passenger or freight traffic, and, if for the latter, whether it is to be heavy or light. This influences the grades, and, therefore, also the length and cost of the road. The heavier the traffic, the more expensive will usually be the first cost of construction, for hills will have to be avoided or cut through, that would otherwise have been run over, thus augmenting the expense by reason of either the increased length of line or the greater quantity of material to be moved. On most roads the heavy freight goes in one direction, so in that direction the upgrades should, if possible, be the lightest. Another reason for having two maximum grades is that, in case a summit is to be reached, the engineer, by having a light maximum down grade in the direction of the line, will be prevented from making the profile too irregular. Having given, then, the *terminii*, intermediate points and perhaps also the maximum grades, an exploratory survey is made by an experienced engineer passing over the country, so as to report whether, in his opinion, a practicable route can be found, and, if so, what would be its approximate location. If the character of the country permit, he travels on horseback; though usually, it is necessary to go on foot, in which case he is accompanied by one or two packmen. His equipment need consist only of an axe, a pair of field glasses, a note book, a hand level or two barometers and a pair of steel climbers to enable him to climb a tree with facility. By means of the latter he will often be able to obtain a good knowledge of the country, and to take such general observations as may be of use in the preliminary survey. He must estimate distances and elevations, or obtain the latter by means of the barometers or hand level, make notes as to the course of rivers and streams and their crossings, establish the general direction of the chains of hills, locate passes, look out for water communication or some other way to obtain access to the differ-

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ent parts of the line, so as to facilitate the forwarding of supplies, and, in short, acquire the greatest amount of knowledge of the country in the least possible time. Upon his report depends the

PRELIMINARY SURVEY,

the party for which should consist of a chief, a transitman, two levelers, two rodmen, a topographer, one or two picketmen, two chainmen, five axemen for the line, and one for each leveling party, three to six or even eight packmen, and sometimes a commissariat officer and an explorer.

As in most preliminary surveys, the duties of any one of these officers are substantially the same. The instructions of the chief engineer of the Canadian Pacific Railway to the Staff may be taken as a general illustration of their character. The gentleman placed at the head of a party is required to take general charge of it, and is held responsible for the execution of all instructions, as well as for the maintenance of proper discipline in the party. Every member of the party is under his charge and must obey his orders. In conducting the survey, he is expected to be at its head every day, exploring in front and to the right and left of the line, in order to see what obstacles may be in the way of the same, and, if serious, decide as to the best manner of avoiding them. When he finds it necessary to leave the party, or in the event of illness, he should nominate the person to act in his place for the time being; in the event of his failing to do so the transitman should take charge.

The duty of the transitman is to run the instrument, keep the notes, and in case there is no topographer, to take the topography.

The duty of the first leveler is to make a profile of the line and cross sections; that of the second leveler is to check the bench marks and to assist in cross-sectioning.

The principal duty of the others of the party is to obey all orders with diligence and to the best of their ability.

Before starting the survey the transit should be set up over the terminus and a true north and south line determined by means of an observation of the pole star. To do this, place the instrument at zero, choose some well-marked point, set the cross hairs upon it a little before dark, and see that no one disturbs the transit between that time and the time when the observation is to be taken, the hour for which can be found in the Nautical Almanac. It is usual to observe the star when at its greatest eastern or western elongation, but it can be observed when at its maximum depression below or elevation above the pole, when the instrument is provided with a tangent screw to produce a slow motion in a vertical plane. In the latter case no correction is required, so when the star has reached its greatest elevation or depression, which can be ascertained by keeping the intersection of the cross hairs on the star, being careful never to pass it, and noting when it appears to cease rising or falling, all that is necessary is to take the reading of the horizontal circle, which will give the angle that the line from the terminus to the point chosen makes with the true north. In observing the greatest elongation, keep the vertical hair on the star and note when it appears to cease changing its azimuth, then take the reading, which will be the angle that the above-mentioned line makes with the vertical plane through the star at its greatest elongation. The correction for this angle can be found by a very simple rule given in the Nautical Almanac, and is to be added, if the star lie between the pole and the line, and to be substracted if it does not. Should the line lie between the pole and the star, this will give a negative result, which shows that the angle so obtained is to be laid off from the pole towards the star; *i. e.*, if the elogation be east, the bearing given by the minus angle will be east. It is easily seen that the latter method is by far the better, for it is necessary to use only the horizontal tangent screw (the one which gives the upper motion, of course), while in the former both the horizontal and vertical screws have to be turned at the same time. Having found, then, the true bearing of a fixed line, the true bearing of the initial line of the survey can be easily ascertained by measuring the horizontal angle between the two lines.

Suppose the party all ready to start and the initial bearing taken. The axemen go ahead clearing the line and the

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chainmen follow, driving stakes about three feet long and two inches wide firmly at every hundred feet, numbering them consecutively, with red chalk as they go. When it is necessary to change the instrument, either on account of the distance of the picketman, who has been keeping the axemen on line, a sudden rise or fall of the ground or a desired change of direction, the transitman gives the signal previously agreed upon for "hub," the picketman chooses a convenient spot for setting up and finds "point" on the line into which one or two of the axemen drive a stake from four to six inches in diameter, and from one to six feet long according to the quality of the ground, and the picketman finds "point on hub" into which he drives a nail.

The transitman then sets the back picket, which in bush work is a small straight sapling whitened on one side, with a cross-piece eight or ten inches long, held in a cleft near the top, picks up his instrument, moves on to the new hub, over which he sets up, sights to his back picket, reverses his instrument and starts the axemen and chainmen to work. Before giving hub again, the transitman should sight once more to the back picket in order to satisfy himself that his instrument has not been moved, and if uncertain of the adjustment should turn the instrument round 180° by means of the lower movement, sight to the back picket, reverse and give "second point on hub." If this coincides with the first one all right, if not, then the distance between the two (measured, of course, at right angles to the line) must be bisected accurately and the nail be driven at the point of bisection. This is, in fact, performing the second adjustment of the transit. Beside each hub, at a distance of about three feet, should be driven a large stake called "hub stake," five feet long, at least five inches in diameter and squared at the top. On it should be written the *exact* chainage of the point on hub, and the distinguishing mark of the survey party, which is usually one or two letters. In setting up in swampy ground, "legs" or long heavy stakes should be driven flush with the surface of the ground, in order to provide a tolerably firm "set up" for the nstrument. The plumb bob is brought *nearly* over the nail by driving down first one leg and then another, then moving the feet of the tripod until the point of the plumb-bob exactly covers the nail. If the instrument having a shifting head much time and trouble will be saved. Hubs should be placed at the summits and bases of hills, so as to avoid as much chopping and moving of the instrument as possible. At intersection points the hub-stakes should be marked "apex," and the angle to right or left should be written on another of the squared faces. The best kind of a hub is the stump of a tree that comes directly on line, for it cannot be knocked out of place. In running through comparatively level country it is well to keep as much as possible to the low ground without lengthening the line greatly or making it too crooked.

It is to be remembered that the survey is not a final one, so that it does not pay to turn out for a small ridge, but to go over it and take a cross section on the summit to where it tails off. In case of trying to reach a summit, it is necessary to follow the contours of the hills so as to obtain a gradual rise. In hilly country where the line rises and falls in long stretches, the best way to proceed is to follow up a stream to near its source, then cut across the divide and follow down another stream on the other slope. If the banks of a river are high, a good crossing can often be found by going up stream, where they are usually lower. In crossing a lake on the ice soundings should be taken, as it might be found desirable to drain the lake.

Offsets usually are taken at right angles to the line, but sometimes inclined. Short ones can quickly be turned off by standing on the centre line, stretching the arms at full length along the line, then bringing them suddenly together; with a little practice a right angle can thus be turned quite accurately. For long distances it is necessary to use an instrument of some sort, a cross head being as good as any. Offsets are needed to locate the bases of hills and the edges of streams. Traverses of ridges or rivers are most easily made with the compass, provided there is no local attraction, by setting up at every alternate station and reading the bearing of both lines intersecting at that point. The compass is sometimes used on the main line in level

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country where there is no great local attraction. Very often there is no instrument used at all, except at the angles, the long tangents being run in by pickets. It is surprising with what accuracy work can be done by the compass and pickets in a comparatively level country. Running a picket line in the bush is quite a different affair from what is taught at the R. P. I. during the chain survey, it may therefore be well to describe the operation: The pickets are thin straight saplings, about five and a half feet in length, brought to a long fine point at the top, and sharpened at the lower ends for pushing into the ground. The tops of two of them are set on line by the instrument about fifty feet apart; a third is then set about fifty feet farther on, the top being brought exactly on line with the others. A check on the work can always be obtained by glancing back along the line and ascertaining if the last three or four pickets are in one straight line. A pair of field glasses is of great assistance in picketing. To "tie on" to an old line, set a hub on each side of it, drive a nail in each along the line of sight of the instrument, and stretch a string tightly between the nails. Next take up the instrument, set it up on the old line, and in its direction, and sight to a picket moved along the string until covered by the vertical hair; then drive a hub and set a nail at the point thus found.

After the transit party has made a good start, the levelers commence work; they should never approach the transit closely enough to disturb the back picket. If the second leveler finds a difference of more than one-tenth of a foot between benches, the levels should be rechecked. The speaking rod is almost exclusively used in bush work; it is much better than the target rod for rapidity, and the leveler is not at the mercy of his rodman, who may often be too ignorant to read the rod. Care should be taken to equalize back sights and fore sights, and neither should exceed for accurate work four hundred feet. It is possible to read an ordinary rod on a clear day at eight or nine hundred feet, but one cannot rely on levels so taken. The best kind of level for rapid work, as far as my experience goes, is the Pastorelli. It is fourteen inches in length and has a ball and socket joint, by means of which it can be set up in places where it would be impossible to use an ordinary Y level. The telescope being an inverting one may cause a little trouble at first, but it does not take long to become accustomed to that. The best kind of rod is a piece of well-seasoned pine wood sixteen or eighteen feet long, four inches wide and one and a-half inches thick at bottom, three inches wide, and three-quarters of an inch thick at top, and divided into tenths and half-tenths. The form of level book should be that shown in the figure below:

Sta.	B.S.	Int.	F.S.	H.I.	Elev.	Remarks.

The F. S. column is for *turning points alone*, so that by adding up the B. S. and F. S. columns, subtracting one from the other, and comparing the remainder with the difference in elevation of the starting and final points, a check on the accuracy of the book can be obtained. Bench marks should be made about every fifteen hundred feet, and should be well defined so as to catch the eye readily. The ordinary method of making them is to blaze the side of a tree or stump, drive a nail into a projecting knob on the root and write the elevation of the top of the nail on the blazed part, together with the distinguishing mark of the survey party. The exact location of the bench should be noted in the level book in the column for remarks. To make a good bench mark without the use of a nail, slice off the side of a stump to very near the bottom, and bring the remaining part to a rounded apex.

The leveler should note every stream and river crossed, its size, direction, level of surface, difference of levels between high and low water, velocity of current, probable discharge, and any peculiarities which it may seem to possess. While in the field it is not necessary to work out the elevations of intermediates; it is sufficient to know the height of instrument

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and the elevations of bench marks. Every evening the leveler should "make up" his book and plot the profile. Leveling can be done very rapidly in winter, as traveling on snow shoes is so much easier than ordinary walking in the bush. The uncertainty as to the shape of the ground beneath the snow makes it sometimes difficult to get a good set-up, but if the three legs of the tripod be kept vertical and the snow be packed well about them, the instrument will be kept as steady as in any ordinary set-up. If the rodman carry a three-foot stake to be pushed through the snow to the ground at intermediates, and upon which the rod is placed, much time may be saved. In this case care should be taken to add three feet each time to the reading of the rod. The transit book ordinarily used has one page ruled into squares, each side representing one hundred feet, and the other page ruled for remarks, a red line running through the center of each. In case there be a topographer in the party, the transitman need make note only of the chainage, magnetic bearings and deflection angles, being sure to state whether they are to right or left. But if there be no topographer, it will be necessary for him to keep fnll topographical notes. These consist of offsets to right and left wherever necessary, contours of hills, courses of streams, observations as to the quality of timber and soil, location of ridges and lakes, etc., etc.

The first entry in a note book each morning should be the name of the person acting as transitman, leveler or topographer, as the case may be. All notes should be clearly and distinctly made in pencil on the spot; no additional notes should be entered with the original notes after the day on which the latter are written. Field notes should not be inked or changed in any way; copies of them may be made in ink and reduced levels entered in ink. This is to prevent what is called "cooking" the notes, an offence of which no true engineer is ever guilty. Any man found tampering with the level notes or benches, or trying any scheme to make poor work pass for good, gets his discharge without any compunction on the part of the chief engineer or those who are interested in seeing work well done. A plot of the day's work should be made every night and the latitude and departure worked out. Checks on the work should be made as often as possible. The check for deflections is made by taking an observation of the pole star every ten or fifteen miles and comparing the reckoned true bearing with the observed, after making the proper correction for conveyance. This is found as follows: Let n= the number of miles in a degree of longitude, a quantity depending upon the latitude of the place, then will $60 \div n$=the correction in minutes per mile of longitude. Calling m the number of miles of longitude between the two points considered, $60m \div n$ will be the required correction. A check for the distance can be roughly obtained by ascertaining the latitude and longitude of various points along the line, by observations of the stars. Checks can sometimes be obtained by tying on to old lines. If an error be found in the direction of the line, it may have been made by recording an angle to the wrong side; to ascertain if such be the case, divide the error by two and see if there be an angle on the plot which is equal or very nearly equal to this result. If there be one the chances are that the mistake was made in that way. In case the error cannot be located, it will be necessary to go over the work again, commencing at the point where the next to last observation was taken. Errors are sometimes made in reading a deflection angle, and sometimes by making a crook in the line owing to the transit being out of adjustment or level. Whenever an observation of the pole star is made, the variation of the needle should be noted. As the survey progresses, the engineer in charge should project a location line on the map by means of the cross sections taken to right and left, in order to give a general idea of where the true location of the road will be. He is expected to keep a diary in which to note the progress of the work each day, the difficulties overcome, and everything relating to the survey. He should see that the camp is properly supplied with everything needed, and should, if possible, have depots for provisions made at points near which the line will pass, so as to avoid packing them over the line. Camp should be moved every three or four miles, in order to avoid long walks

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to the place of starting work in the morning. It may be necessary during the progress of the survey to forward special instructions to the engineer in charge; for this and other reasons, that officer should take especial care that whenever the camping ground is changed, a notice be distinctly written upon a tree, or in some other conspicuous position, containing the following information:

1. The distinguishing letter of the survey.
2. The number of the camp.
3. The date of removal of camp.
4. The probable direction and distance to the next camping ground.
5. The name of the engineer in charge of the party.

The success of the survey is materially assisted by each man endeavoring to save as much time as he can. A few hints as to how this can be effected may be of use. Before moving the instrument the transitman should, if he wish to prolong the line, set two pickets on line *beyond the new hub*, in order that the axemen near continue their chopping while he is moving on and setting up. He can set his own back picket, if it be left ready for him, by placing it close behind the instrument and bringing the cross to the level of the eye-piece. As soon as point for hub is called for, one of the axemen should commence making a hub, and if the ground require it, legs for the instrument. The fore chainman, who carries a light axe, should occupy himself in cutting stakes when not busy chaining.

There is a great variety of opinion as to what transit is the best for bush work. Some engineers prefer those of English manufacture, others those made in this country. The most satisfactory that I have ever tried is one of Gurley's manufacture.

LOCATION.

After the results of the different preliminary surveys (if there be more than one) have been handed into the office, it is there decided what is to be the approximate location of the line. The party for location is the same as for preliminary, except that there is no explorer needed. The general style of the work is the same, the principal differences being that, as the survey is a final one, the centers are run in on the curves, and greater care is taken in getting the elevations of points between the stakes and on the cross sections. The subject of curves is so well treated in Henck's Field Book for Engineers that it is useless to go into it here. It will be sufficient to state that the formulæ most often employed are $T = R\tan \frac{1}{2} I$ and $C = R \tan \frac{1}{2} I \tan \frac{1}{2} I$, where T is the sub-tangent, R the radius of the curve, I the angle of intersection and C the crown distance. The latter is used as a check for the correctness of the first half of a curve, which is so long as to require several changes of instrument. The number of stakes put in at one setting-up depends altogether upon the natural features of the ground, the degree of the curve and the size and thickness of the timber. In running around a rocky bluff it may be impossible to see more than one hundred feet at a time, especially if the angle of deflection be large; in which case it would be well to put in stakes fifty feet apart.

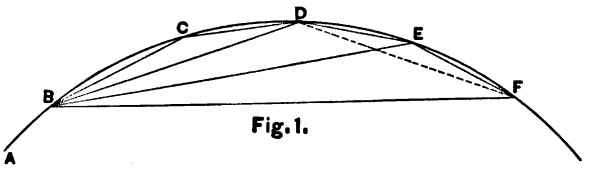

Fig. 1.

In Plate I., Fig. 1, suppose the transit to be set up at B to run in the curve BCDEF, &c., from the initial tangent AB. If the points C, D, E and F are all to be located from the point B, it will be necessary to clear out all the timber on the area included between the chords BC, CD, DE, EF and FB. Now if the curve be an easy one, that is of light curvature, say thirty minutes, that area will not be great, so that it would take less time ordinarily to do that amount of chopping than to make a new set-up at D, in which case the areas of the triangles BCD and DEF only would have to be cleared. If the curve were heavy

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it can easily be seen that time would be saved by making the two setting-up. Before commencing the chopping, the transitman decides how many stations he will lay off and sets a picket on each extreme chord (BC and BF in the case taken above) at a short distance, say twenty feet from the instrument, so as to serve as a guide for the axemen. One slight difference between laying out a curve in the field and the explanation usually given in text books for doing it, should be noticed. In text books the first chord is taken to be one hundred feet, while in practice it very rarely occurs that *a* B.C. (beginning of curve) comes at an even station, so that the first chord is nearly always less than a full chain, and the first deflection angle will be equal to the difference between the chainage of the B.C. and that of the next full station divided by one hundred and multiplied by one-half the degree of the curve; for example, if the chainage of the B.C. is 1021+54.6, and it is a three-degree curve, the first deflection angle will be $\frac{1022-1021+54.6\times 1°30'}{100}$ $=\frac{45.4}{100}\times 1°\ 30'=0°\ 40'\ 52''$ nearly, or in practice 0° 41′. The second angle of deflection will be 2° 11′, the third 3° 41′ etc. If the length of the curve be 925 feet (=100 I÷3°), the chainage of the E.C. (end of curve) will be 1030+79.6, the last chord will therefore be 79.6 feet long and the corresponding deflection angle, or increase of deflection angle, as the case may be, will be $\frac{79.6}{100}+1°\ 30'=$ 1° 11½′. By 1030+79.6 is meant 1030 chains and 79.6 feet; it is always written thus on the hub stakes. The degree of a curve should be made as small as possible, for the longer the curve the shorter the line; the "lay of the ground" nearly always decides the degree of curvature to employ in connecting two tangents, that curve being chosen which will give the best profile, or in case of a choice between rock and earth excavation, *the least expensive line*, the limiting value of the degree of curvature, of course, being never exceeded. This limiting value was decided upon at the same time as that for the grades. Where a grade and a curve occur together, a resistance to motion is caused by each, so to make the effect not exceed that due to the maximum grade on a straight line, the limit of the former has to be changed. It has been found experimentally that a one-degree curve causes as much resistance as a 2.4 feet rise per mile, so that the limiting value for grades will have to be reduced by that amount for every degree of curvature. The value 2.4 was found for a speed of twenty miles per hour.

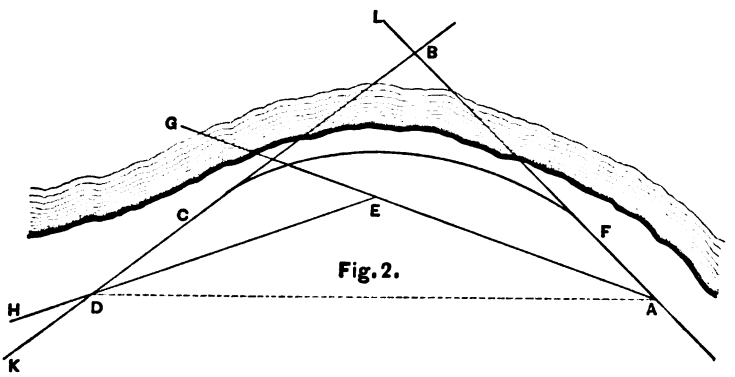

Fig. 2.

Locations are sometimes made by taking the angles and distances directly from the plot and laying them out upon the ground, but the ordinary way is to use the plot simply as a guide, and to run in the tangents and put in curves to fit. In going around a rocky shore the intersection points often fall in the water, as shown in Plate I., Fig. 2. To run in the curve F C, run the random lines A E and E D, measuring the angles B A E=i, G E D=i_1 and H D K=i_2, then L B D=I=$i+i_1+i_2$. In the triangle E A D, E A, E D and the angle A E D are known, so that D A and the angles E A

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D and E D A can be computed. This will give the angles B A D and B D A, so that in the triangle B A D, the sides B A and B D can be found. After deciding upon the degree of the curve, the sub-tangent can be calculated in the ordinary manner, the differences between this distance and the lengths A B and B D be laid off from the points A and D, and the curve run in as usual.

If several location lines have been run in the same neighborhood, the stakes on the one adopted should be painted, so as to readily catch the eye.

CONSTRUCTION.

The first steps to be taken after the final location has been decided upon is the clearing of the right of way. The width of clearing should be about one hundred and thirty feet, in order to allow for high banks and wide side ditches, and for the erection of a telegraph line, which should be placed on the berme, or space between the foot of the slope of the bank and the side ditch, and always on the same side of the line. As a wide clearing is necessary to prevent trees from falling on the wires, the center line of the road should not pass through the middle of the clearing, but far enough to one side to allow the telegraph line to occupy that position. Assuming the average fill to be three feet, the top width of bank to be seventeen feet and the slope ratio of the sides to be one and a-half horizontal to one vertical, this would make the slope stakes extend thirteen feet from the center line, so if the latter be fifty feet distant from one side of the clearing and eighty feet from the other, the telegraph line could occupy the center. If by reason of a high bank or a deep cutting the telegraph line be brought too near one side of the clearing, the latter should be widened there; and in any case, all trees which by falling, would strike the wires should be cut down. The trees felled on the clearing should be winrowed and burned, and any logs left by the fire should be hauled into the bush or be burned a second time. After the line has been properly cleared, *and not until then*, should the section engineer commence operations. His first duty should be to lay out the off-take drains, for full directions concerning which, and railroad drainage in general, see an article on the subject in the "Pi Eta Pamphlet" of 1878–9.

He should next re-establish the center line, for most of the stakes and perhaps some of the hubs will have been destroyed during the clearing. While doing this he should reference all hubs at the beginnings and ends of curves, and on tangents at least one in every two thousand feet, and at apices in the grade, in order to facilitate the finding of the center line after the grading is finished. The ordinary method of referencing is to turn off an angle of 45° to the tangent, set a hub at 100 feet, driving a hub stake beside it with R. H. marked thereon, reverse the instrument and place another in the same manner; then turn off an angle of 45° to the other side of the tangent and proceed as before. Should the natural features of the country or any other cause prevent the setting of hubs on both sides of the line, it will be necessary to set two hubs on each reference line, as shown in Plate I., Fig. 3. Care should always be taken that the hubs are placed in positions where they would not be liable to be disturbed.

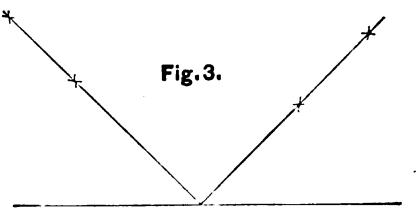

Fig. 3.

I have employed the following method and prefer it to any other, although it was not in accordance with the instructions given to the section engineer of the road on which I was working: Set up the instrument over the hub to be referenced, turn it until two trees are found on line with the hub, and cut down the most convenient one close to the ground, so that the instrument can be set up over the stump. After having clamped the plate, set a nail on the stump, then reverse and set another on a blaze upon the other tree. Turn the instrument at about right angles to this reference line, find to other trees on line and proceed as before. By this means the hubs are set so permanently that even fire will not destroy them. Their

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positions should be accurately noted in the field book.

The next step should be to to run over the levels very carefully, placing benches at every thousand feet on the edge of the clearing most distant from the center line, so as to be out of the way of the graders. Benches should be always placed at both ends of heavy cuttings for easy reference in driving grade plugs, during the progress of the work. Where the line does not pass through wooded country and no convenient object can be found for a bench mark, one should be made by sinking a post in the ground five or six feet in order to be below frost, and marking the elevation of a nail driven in the top of it upon a stake placed alongside. Plugs two inches in diameter and six or eight long should be driven at the foot and directly in front of each center stake. They should be made level with the service of the ground, and upon them the leveling rod be held when levels are taken. Should the plugs not be driven to the surface, it will cause a large discrepancy between the actual quantity of material excavated and that called for by the profile. If the section engineer would like to avoid all chance of receiving an overhauling from the office, on account of such discrepancy, he can do so by clearing away from the foot of each stake all moss and spongy material and driving the plug down to solid ground. In this way the true level of the base of the embankment would be recorded, for all the moss, etc., is compressed to almost nothing by the weight of the superincumbent earth. It may be unnecessary labor, but it is well to look ahead a little, especially if those in charge of affairs are at all inclined to be unreasonable.

After the profile of the line has been made on profile paper to a scale of 200 feet to the inch horizontal, and 20 vertical, the gradients should be carefully established. The objects to be attained in fixing them are an equality of cuts and fills to as great an extent as is judicious, and the avoidance of long hauls and irregularities in the continuous grade line.

The next thing to be done is to write the cuts and fills on the center stakes, at the same time setting the slope and ditch stakes. To set the former when the ground does not slope greatly, add together (for earth cuttings and embankments) one-half the width of road bed (ordinarily 11 feet for cuts and 8½ feet for fills), the center cut or fill and half the latter quantity; measure off the distance so found at right angles to the center line, *estimate* the rise or fall in that distance, add to or subtract from the distance three halves of the rise or fall and hold the rod at this new distance. The level having been previously set up and the height of instrument above grade determined, sight to the rod, subtract the reading from the latter quantity, and add to it one-half the width of road bed and one-half of the quantity itself. Should the sum thus obtained equal the distance of the point, where the rod is held, from the center stake, set the slope stake there; if not, try again until the two quantities agree within two or three tenths of a foot. Set the ditch stake outside of the slope stake at a distance equal to the width of berme, which varies from six to fifteen and even twenty feet, according to the stability of the material, the most common value being ten feet. On the slope stakes should be marked *s. s.*, and their distance from the center line; the ditch stakes should be marked D. In grading side ditches it is a good plan to drive a plug four or five feet outside of the ditch stake and mark on the latter the cut below the former.

At the same time that the slope stakes are being set, elevations should be taken on every cross section at distances not equal to the semi-width of road bed, and wherever the slope changes; they should be taken, too, at some distance beyond the ditch stakes. Cross sections should be taken and slope stakes set wherever the slope of the ground or the grade changes. Cross sections should be set out instrumentally at right angles to the center line on tangents; and on curved portions at right angles to the tangent of the curve.

The levels on the cross sections should be taken in the same manner as those on the longitudinal line, commencing on a bench mark, and using the same datum; they should be continued through a series of cross sections till another bench mark is reached, on which a level should be taken to test the accuracy of the work.

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Grade plugs should be driven at the ends of cuttings, where the grade cuts the natural surface, both on the center line and at a distance on each side equal to the semi-width of road bed in cuttings. Driving a grade plug where the grade is level is quite an easy matter, for all that is necessary is to make the rodman hold his rod, at different points, until the rod reads an amount equal to the difference between the height of instrument and formation level: but when the grade is a rising or a falling one, the change in the height of formation level must be taken into account every time that the rodman moves the rod in the direction of the line. It is sometimes customary to drive, at the ends of large cuttings, grade plugs two or three feet long and as many inches in diameter, the upper end being bound with an iron ring so as to be useful as a rough reference during the course of the work. The form of level book used on construction differs somewhat from that used on preliminary, and is given below.

Sta.	B. S.	Int.	F. S	H. I.	Elev.	Grade.	Cut.	Fill.	Remarks.
.....	3.26	..	..	1128.30	1125.04	..	..	..	B. M., No. 23.
1320+55...v...	..	11.21	..	..	1117.09	1116.55	0.54	..	Grade 1 per 100.
R. 11.....	..	10.20	..	..	1118.10	1116.55	1.55	..	....
R. 14, s. s.....	..	9.80	..	..	1118.50	1116.55	1.95	..	....
L. 8.5.....	..	13.20	..	..	1115.10	..	..	1.45	....
L. 13.5 s s.....	..	14.40	..	..	1113.90	..	..	2.65	....
L. 30.....	..	16.80	..	..	1111.50	..	..	..	....
T. P.....	..	..	0.28	..	1122.02	..	..	..	....

The notes here given show the center levels and the cross sections taken together, as would be the case were the benches run in by flying levels. In setting slope stakes in swamps it is not necessary to use the instrument: simply set them at the distances called for by the fills marked on the center stakes, allowing a little for the subsidence of the surface, if it be thought advisable.

Before commencing to work a cutting, the quantity of material in it and its quality should be determined, so as to decide how much should be carried each way, and to ascertain how far it will complete the embankment at each end, due allowance being made for the shrinkage of the material. The ground is now ready for the contractor to set the graders to work.

As stated in the article in the Pi Eta Pamphlet, already referred to, he should commence operations at the ends of the off-take drains and continue them across the right of way to the opposite side ditch, in order to start four gangs of men in each large depression of the line to build the embankment from the side ditches. While the embankment is being built, both the contractor and engineer should keep an eye on the graders, especially if they are doing piece work, so as to see that the close cutting and grubbing are properly attended to, and that no poor material, such as roots, moss or logs, is thrown in the bank. The last, unless very large, should be kept higher in the middle than at the sides all through the progress of the work, and when finished the upper surface should be rounded off so as to fall from four to six inches from center to sides. It should be left considerably above grade, so as to allow for subsidence, the amount being determined by previous experience.

By the term "grubbing" is meant tearing the stumps out by the roots, and by "close cutting," chopping them down nearly level with the ground. Grubbing occurs on the off-take drains, on side ditches, in embankments under two feet in depth, and in line cuttings, though it is not often paid for where the cutting exceeds three or four feet, or in borrow pits. Close cutting should be done in enbankments over two and under five or six feet in depth. A safe rule to go by is, "never to allow a stump to reach within two feet of grade," for the latter may some time be lowered if the bank should sink uniformly below the original grade. It costs more to chop one pro-

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jecting stump out of the bank than to close cut a dozen before commencing the grading.

Before opening an earth cut the engineer should see that the side ditches are finished as far as the embankment will extend, and that the material excavated from the former is cast into the latter. In shallow cuttings it is sometimes necessary to excavate below grade in order to remove all the loose surface material, and to fill either with ballast or firm earth taken from a deeper portion of the cutting or elsewhere. All large stones and boulders measuring less than 27 cubic feet, and all loose rocks that may be removed with facility by hand, pick or bar, without the necessity of blasting, are classed as "loose rock." All stones and boulders measuring more than 27 cubic feet, and all solid quarry rock are classed as "solid rock." In cuttings composed of both earth and solid rock, a berme of six feet is to be left on the upper surface of the latter. Owing to its removal, earth shrinks from eight to twenty-five per cent. of its volume, loose rock changes but little and solid rock occupies one and a half times the space in embankments that it did in its natural state. Earth cuttings and embankments have slopes of one and a half horizontal to one vertical; rock cuttings, one horizontal to four vertical, and rock embankments one to one. Where the side ditches and line cuttings do not furnish enough material for the banks, borrow pits are rendered necessary. To lay one out, fix a line far enough from the pit not to be disturbed by the excavation, and divide up the surface of the ground that is to be removed into squares, whose sides are parallel and perpendicular to the line of reference, then take the elevations of the corners of these squares above the datum used on the line. After the borrow pit is finished, re-locate the corners of the squares and take their new elevations. This divides the volume removed into vertical square prisms, whose length can be found by averaging the differences of the two elevations taken at each corner. If the length of the sides of the squares be taken equal to some multiple of three feet, the calculation of the cubical content will be greatly facilitated. Thus, if the length of each side is thirty feet or ten yards, the horizontal section is one hundred square yards. If the average of the differences of elevations at the four corners of any square is twenty-seven fee or nine yards the cubical content of the prism will be nine hundred yards. Station grounds should be laid out, if possible, on long tangents where the grade is nearly level; or at least does not exceed nineteen feet to the mile. If it is necessary to place one on a curve, let the station house be situated near the apex, to allow the station master to see trains approaching both ways. Clearings of eight or ten acres should be made about station houses to provide against danger from bush fires, if for no other purpose.

Very unstable swamps or muskegs are occasionally crossed by the method called "logging," which consists in placing logs transversely to the line under the bank, leaving their ends projecting at least six feet beyond the bottoms of the slopes. When this is done, the ground must not be broken for side ditches.

Sloping ground covered with pasture should be ploughed to prevent sliding, before the embankment be built thereon.

Measurements of material removed, should, whenever possible, be taken in excavation, and, when taken in embankment, due allowance should be made for both shrinkage and subsidence of the natural surface. Preliminary estimates are made from the profile by averaging end depths; quantities in ditches are taken out by the method of "end areas;" and in cuttings by either the last mentioned method, or by the "prismoidal formula," which is given by the equation $V=l\div 6(A+4M+B)$, where V is the cubical content, l the length between the sections, A the area of one cross section, B that of the other, and M that of the cross section, which is not measured on the ground. Its value can be obtained by reducing each end area to an equivalent area between parallel bases by the formula $h=\frac{1}{3}(\sqrt{6A+b^2}-b)$, where b is the width of road bed and h the depth of the equivalent area, and calculating the area corresponding to the mean of the two depths thus found. It is sometimes obtained by calculating the area of an assumed cross section, all the variable dimensions of which are taken to be a mean between the corresponding dimen-

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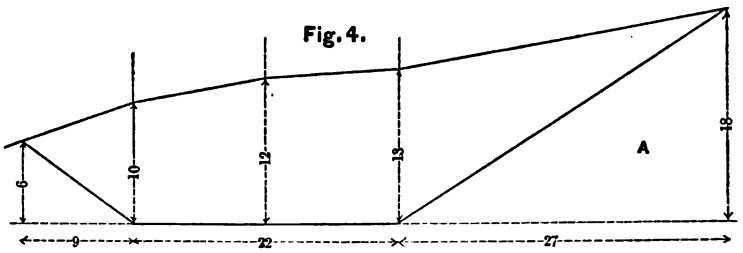
sions of the two end sections. The following example will serve to illustrate the different methods mentioned.

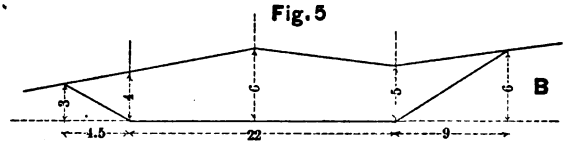
The easiest way to calculate the area of a cross section, whose dimensions are given, as in Figs. 4, 5 and 6, Plate I., is to add together twice the center depth

Fig. 4.



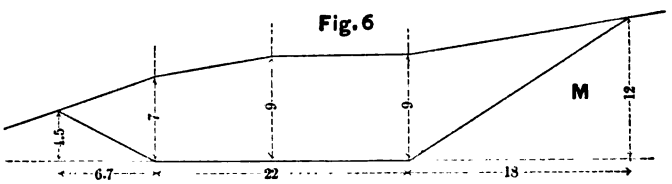
and the depth at each side of the road bed, multiply the sum by the width of the latter and divide by four. Then multiply each of the side depths by the horizontal distance of the slope stake from the side of the road bed, add the results together, divide by two and add

Fig. 5



to the quotient the area first found. By so doing there will result in this case, A=479 sq. ft, B=147 sq. ft., and M=291.5 sq. ft. (from diagram). By the rule first given, M would equal 295.4 sq. ft., which shows how closely the two methods agree.

Fig. 6



If l=100,

By mean depth,....	V=1072	cubic yards.
By end areas,.....	V=1159	" "
By prismoidal formula, 1st case....	V=1116	" "
By prismoidal formula, 2d case....	V=1106	" "

The method of end areas always gives an excess, and the method of mean depths a deficiency. An average of the two in this case gives 1116.5 cubic yards, which agrees almost exactly with that obtained by the prismoidal formula—this merely accidental, owing, perhaps, to the similarity of the sections. On uneven ground cross sections ought not to be taken far enough apart to make the area of one more than double that of the next. In Henck's Field Book can be found formula for many special cases of earth measurement.

The office work of a section engineer comprises the making of a working profile and plan, and the filling out of a section book, cross-section sheets and return sheets. On the profile the final gradients should be drawn in red and the surface of the ground in black. It should be completed by drawing black vertical lines at every 100 feet, on which should be written in black figures the height of the surface of the ground above datum, as ascertained by the levels taken on the plugs; immediately above these should be placed the formation level in red figures; the height of fills should be placed below the surface heights, and the depth of cuts above formation level. Cuts and fills should be written in black figures having been as-

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certained by subtracting surface and formation levels, the one from the other. At each change of gradient, the vertical lines should be in red and the height of formation level written in the same color, but with larger figures than at the intermediate stations. Where side ditches occur they should be indicated by blue lines at the level of their bottoms, and the center depth of cutting should be marked in blue figures on the black vertical lines. At the bottom of the profile should be shown, in blue, the curves in the line, with the stations where they begin and end, as well as their degrees of curvature; and at the top should be indicated the quality of the timber and ground, stream and road crossings, culverts, etc. In preparing plans, all *existing objects*, as roads, buildings, fences, etc., should be drawn in black lines; water should be indicated by a blue tint; and works *to be constructed*, as deviations of roads and streams, also the center line of the railway and the limits of land required for railway purposes should be shown in red lines.

The section book should be filled up so that it will form a complete and accurate record of all the longitudinal and transverse measurements and levels. In the upper portion of each page should be entered, in the proper place, the chainage to every station and intermediate point on the center line, each change of gradient, with its rate of inclination, the height of surface as well as formation level at each station and intermediate point, and the corresponding depth of cutting or filling. The lower part of the page should have every cross section regularly entered, giving the distances on each side of the center line, and the height above or depth below formation level; the slope stakes should also be designated. Tables of bench marks and reference hubs should be made at the beginning of the section book. Cross sections are plotted on paper ruled for the purpose into squares, each square representing one foot; their dimensions and areas should be marked thereon. The return sheets, which are large, should be ruled horizontally and vertically, and on them should be kept an account up to date of all material moved or used on the section. The vertical columns, which are of varying width according to what is to be written in them, should contain the following quantities (with others if need be), though not necessarily in the exact order here given: Stations from and to, clearing, close cutting, grubbing, line cutting, side ditches, borrow pits, off-takes, catch-water drains, rip-raps, masonry, stone drains, pole drains, piles, lumber, ties, timber and totals. The divisions, line cutting, side ditches, and off-takes should each be subdivided into three columns for earth, loose rock, and solid rock, borrow pits and catch-water drains into two each, for earth and loose rock; piles into two, for amount delivered and amount driven, and the timber into as many as there are different sizes used on the work. Grubbing, close cutting and clearing are measured by the acre; earth, loose rock, solid rock, rip-raps and masonry by the cubic yard; stone drains, pole drains, piles and timber by the linear foot; ties by number, and lumber by board measure. Before making out the first return sheet, the line should be divided into groups so that the cuts and fills will come in separate divisions. For instance, if the chainage of one end of a cutting were 1628+43 and the beginning of the next were 1640+64, the division, which would be for a fill, would be made from the first mentioned chainage to the last, and the quantities recorded would appear in the columns marked side ditches, off-takes and perhaps borrow pits. If the chainage at the end of second cutting were 1648+20, the division would include all between station 1640+64 and that station, and the quantities recorded would appear in the columns of line cutting and catch-water drains. When some of the divisions would thus be rendered too long for convenience in keeping the accounts, it will be necessary to subdivide them, taking, if practicable, the chainage of some natural or artificial feature of the ground, such as a stream, or a culvert opening as the point of division. The column for totals should be divided into three parts, for earth, loose rock, and solid rock. It is filled by adding up the quantities of each kind of material in each horizontal line, and entering the sum on that line in its proper place. After all the columns are filled, add them up vertically and place the sums so ob-

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tained on a horizontal line below the columns, each in its proper place; then adding the total amounts of earth, loose rock and solid rock in this horizontal line (excluding those under the total columns), the amounts so obtained should equal those found by casting up the total columns. To find for what the contractor is to be paid, subtract from each of the totals the totals taken from the last return sheet. In this way can be readily seen by simply examining the return sheet, exactly what amount of work has been done and its distribution along the line.

Many of the directions here given for the manner of doing the office work are taken with very little change from the instructions given to the staff on the Canadian Pacific Railway; but as the officers of that road have devoted a great deal of attention to that subject, I think you will find their methods to be as good as those used on any of the railways on this side of the border.

After the grading has been completed and the ties have been distributed, the engineer re-locates the line on the grade very exactly, using a thin picket and driving thin stakes (lathes turned edgeways will do) at every hundred feet. He also drives very accurately grade plugs near the stations to the height of the rails.

To ballast the line the ties are laid and the rails spiked to them, so that the train can be run slowly over the road for the purpose of distributing the ballast. In unloading, the train must be kept working to and fro so as to thoroughly mix the different qualities of ballast, until a sufficient quantity is deposited for the first lift. The track must then be raised so that there will be an average depth of six inches beneath the sleepers, and the ballast must be well beaten and packed under and around them. As the raising proceeds the end of the lift should extend over not less than three rail lengths, and before trains are allowed to pass over the inclined portion of the track, it must be made sufficiently solid to prevent bending of the rails, or twisting the rail joints. A second lift is afterwards put on in the same manner. In wet cuttings an increased thickness of ballast is often necessary. The surface of ballast pits should be stripped of soil where such exists, and no material whatever should be placed on the road bed but good clean gravel, free from earth, clay, loam, or loamy sand; no large stones should be allowed, the maximum size of gravel being not greater than three inches in diameter.

A good deal more could be said on the subject of "construction," but as I mentioned in the beginning of these lectures, it is not my intention to write a complete treatise upon railroading, so I will refer you for further information to the works of Vose, Henck, Trautwine and Gillespie. However, as some of you may sometime go into contracting, I will close with a few remarks on that subject.

Railroad contracts are let sometimes by the mile, but more often by the cubic yard and other dimensions. To make a successful bid it is necessary to have a very good knowledge of the country through which the line is to pass, so as to be able to estimate the cost of plant, labor, etc. The usual form of tender indicates the probable amount of each kind of material, and the bids are based on these quantities. Now, if the person bidding feels positive that any of these quantities are in excess, and any others in reduction, he can, by bidding low on the former and high on the latter, keep down the sum total of his tender, and yet, if it be accepted, run a good chance of making a reasonable percentage. On large contracts it pays to send an expert over the line so as to ascertain pretty definitely how to bid. Care should be taken in purchasing supplies, plant etc., for the work; a great deal of money can be saved by knowing how and when to buy. Attention should be paid to the transportation of supplies, getting them in sufficient quantity when the rates are low, so as to tide over the time when they will have risen. It does not often pay to sub-let a cutting, owing to the expense of working it; if any one can make anything out of a cutting the contractor himself ought to be able to do it. But in regard to ditch work it is an entirely another affair. Men are unwilling, as a general rule, to undertake such disagreeable employment as ditching, unless they see a good chance of earning big wages. A grader will take out nearly twice the quantity of material per diem when working for himself, as

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when he is paid by the day; so it is worth while for a contractor to sub-let swamp work to gangs of four or five, in which case it is well to make a written agreement with the men, binding them to do good work and to finish within a certain time. To insure the completion of the job, hold back ten per cent. of their pay until they finish everything satisfactorily. Never pay by bank measurement, for the navvies will be sure to fill up the bank with logs and stumps. A common trick of theirs, especially in winter when there is snow on the ground, is to pile about six inches of moss along the edges of the ditches so that when the measurements are made with a tape and rod, the depths will be in excess. In working wet cuttings it is often necessary to corduroy the road bed, both in the cutting itself and on the dump, to prevent the carts from sinking axle deep in the clay. If the engineer is a good-natured fellow, he will allow the ties to be used for the purpose. It does them very little harm, and saves a great deal of expense.

The best way to take out loose rock is by means of sledges. They can be made very cheaply by taking two of the spreading roots of a large tree and bracing them across; no artificial joint, unless it were an expensive one, could stand the stress that comes on the pointed end of the sledge. It is often the cheapest way to take out the gullet of the cut first: in which case it is advisable to allow a slope ratio of one horizontal to four vertical, so that if rock be struck there will be no difficulty in giving it the proper slope. Contractors sometimes find it to be economical to waste the materials from cuttings where the haul is a long one and the allowance for extra haul is insufficient to cover the extra expense. Loose rock is often hauled to the mouth of a cut and there wasted, the contractor replacing it at his own expense by an equal amount of earth. Rock cuts should be kept to the full width and depth as the work progresses, for it is very expensive taking up bottom. Ties should be cut and hauled in winter. It is to the mutual interest of contractor and engineer to keep liquor sellers away from the line.

In contracting, make your own measurements, not so much to keep a check on those of the engineer as to pay the workmen by, and to enable you to see the cost of all the different portions of work.

It is customary for contractors to keep a store for the purpose of supplying the workmen with everything they need for the work. If not carefully watched, they are liable to overrun their account, and, as they express it, to "jump the job."

When sub-letting a piece of work containing loose rock, it is better to bargain for a lump price than to pay so much for one kind of material and so much more for another, because an ignorant man is never satisfied with his measurements, in any case, and naturally counts upon a larger percentage of rock than he is likely to get.

No matter how scarce workmen may be, it is always good policy to discharge a mutinous man; it keeps the rest upon their good behavior. All the men on the work should be cautioned against removing any stakes, benches, or other landmarks of the engineer.

It is necessary, on a contract of any size, to keep plenty of plant on hand, especially such small articles as nails, bar iron, horseshoes, picks, shovels, irons for carts, etc. On this point I can speak from experience; for once, when in temporary charge of a five mile contract, I had to make a journey of one hundred and forty miles, half of the distance on foot through the swamp in order to purchase a few horseshoes, nails and axle irons; and had to have them packed thirty miles over the line. They were pretty expensive by the time they reached their destination. In contracting, as in everything else, it is better to do work well in the first place. One loses in reputation more than he saves in pocket by doing scrimp work, besides, in the end, he may have to expend far more for repairs than it would have cost in the first place to have completed everything according to the terms of the contract.

MM. Grimaux and Adam have recently accomplished the synthesis of citric acid from glycerine, and Kekulé announces that he has been working for the same object, but on different lines. He cannot tell at present whether he has been successful.

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SANITARY ADMINISTRATION IN PARIS.

From "The Architect."

A REPORT has been presented to the Public Works Committee of Birmingham by Mr. Till, the Borough Surveyor, describing his visit to the principal Continental towns. He says that in Paris every possible opportunity was given to him for the inspection of the municipal works. The following are Mr. Till's notes on the water supply, gas, paving, and sewage of Paris:

Water Supply.—Until 1860 all water was supplied by the water company (Compagnie Générale des Eaux). In the year 1860 the City Council bought up all the company's rights and assets for an annuity, during fifty years, of £46,400, payable quarterly. At the same time the said company was constituted the administrative agent of the municipality for all matters relating to the future water supply. The company receives in this capacity a commission fixed thus: On all annual receipts between £144,000 and £240,000, 25 per cent.; between £240,000 and £400,000, 20 per cent.; between £400,000 and £480,000, 10 per cent.; on all over £480,000, 5 per cent. A long and careful inquiry by a special commission has just been completed, and their report presented. The main recommendation in the report is that private consumers shall have meters, and pay according to the quantity of water used. The present system of special contracts according to rent of house is found to be unsatisfactory and exceedingly wasteful. The water supplied to the city is of two qualities; the best comes from the Seine above the city, from the Vanne, the Dhuys, and from the wells, the supply from the latter being about 30 per cent. of the total daily supply. The Seine and other river water is not filtered before being delivered. The temperature of the well water is 39° F. The second quality is from the Marne and the canals. This is used for washing and watering the streets, and for industrial purposes generally, but not for cooking or drinking. It is intended to largely increase the supply of this quality of water, mainly for sanitary purposes. The municipality pays nothing for water used for public service.

Gas.—This does not belong to the city. It is the property of a company known as the "Company for Lighting and Heating by Gas." The charge for public lamps varies with the burner used. Of these there are three sizes, consuming respectively 100, 140, and 200 liters the hour. The charge to the city is, taking these in the same order, and per hundred hours, 1*s.* 3*d.*, 1*s.* 8*d.* and 2*s.* 6*d.* respectively. If supplied by meter the cost is 3*s.* 10½*d* per 1000 cubic feet. The private consumers may agree for so much per hour per burner, or may use an approved meter. In this case the maximum price permitted by law is 7*s.* 9*d.* per 1,000 cubic feet, being double what the city pays. The same applies to gas for heating or for gas engines. The illuminating power is fixed thus: Under a pressure of 3 millimeters, gas burning at the rate of 115 liters per hour shall give a light equal to the light of a Carcel lamp burning per hour 42 grammes of pure colza oil(3 millimeters, 0.12 inch). Where private consumers use meters they pay rent to the company. The city does not pay rent for meters registering gas used in lighting streets, but it does pay rent for those used in municipal buildings of all kinds. The gas company may demand monthly payment in advance. The company is not allowed to demand any other guarantee from the public. Recently a new mode of showing house numbers at night has been adopted. An upright frame in the form of a triangular prism, eight inches long, is fixed against the wall over the door. On each of the two visible sides is a plate of dark-blue glass, having the number in white letters. Inside the prism is a small gas jet. The first cost of this apparatus is £4, including fixing, and the cost of the gas about 22*s.* per annum.

Streets.—Of the whole city street area 73 per cent. is paved, 22 per cent. being macadamised, and 3 per cent. asphalted. It is intended to pave all streets where the traffic is heavy. The dimensions of pav-

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ing stones have been the subject of careful inquiry and experiment, and the size finally adopted has a surface of 6½ inches by 4 inches, and a depth of 6½ inches. On steep gradients larger stones are used. Formerly the size was 9 inches each way. These stones were found to get rounded at the edges and corners, and to present an uneven surface. The steam rolling of the macadamised streets is done by contract, the cost being but little less than horse rolling. The asphalte carriage ways are bedded on beton 4 inches thick, well pressed down (in very wet weather bitumen is used instead, as the beton does not set quickly), over the beton a layer of mortar, and then, at the end of five days a layer of asphalt 1½ inch thick. The annual cost of footpaths of all kinds within the city is £43,600. The cleansing and flushing of streets and removal of house refuse costs annually £160,000. Each ward has its own set of sweepers, &c. Since 1873 a special tax has been levied for sweeping footpaths; previously each householder had to do that duty. There are in all 3,120 men and women employed in sweeping the streets and removing refuse. The street watering on paved streets is done from April 15 to September 30; on others from March 15 to October 15. About 22 per cent. of the area of the streets is watered by jointed pipes, and the rest by watering carts. The *first* mode is stated to cost only *about half as much*, area for area, as the *second* mode, but then the amount paid for horse hire is nearly double that in Birmingham. The watering carts belong to the municipality; the horses belong to contractors. The hydrants used for street watering are about 40 yards apart; the jointed pipes by which the water is distributed are 1 inch in diameter, in seven lengths of 8 feet each, on wheels, the joints being made with gutta-percha, the man with his finger on the nozzle regulating the quantity of water put on. We found in the Rue Castiglione, the carriageway whereof is 22½ yards wide, that it took the man, on an average, thirteen minutes to water only 33 yards in length of carriageway, and as each length is watered he uses a broom to sweep up the horse dung, &c. With one of our horses and carts a man can put on thirty-five loads, of 330 gallons each per day, and this quantity is sufficient to cover 82,000 square yards, or say 2,343 yards per cart load. I do not consider the hose system suitable for adoption here, except in the case of steep gradients like High Street and the Bull Ring, where a horse would work with difficulty. Since 1873 the house refuse has had to be placed each night in convenient boxes, in front of the houses, the contractor's carts calling for and removing the same early in the morning. The removal of this house refuse costs the city £80,000 per annum; formerly it was a source of income to the amount of £20,000 per annum. Two causes are alleged for the change: (1) deterioration in the value of the refuse, owing to the diminished use of *wood* as fuel, and increased use of coal and coke for houses and factories, and (2) increased distance of farms from the city, owing to the increase of suburban villas.

Trees in Streets and Squares.—Of these there are now about 90,000, besides 20,000 in the cemeteries. The roots of the trees planted in the streets and squares have a network of small drains for the supply of moisture. These are connected by a central drain, having a valve, and leading to the main sewer. The average cost of a tree, including transplanting, propping, draining, grid, &c., is £7, and about 90 per cent. of the transplanted trees succeed. There are three nurseries for trees, with an area of 6½ acres. The qualities sought in such trees are (*a*) rapid growth, (*b*) shade, (*c*) non-liability to attack by insects; and the trees selected on these grounds are chestnut, elm, the western plane, lime, and maple. 115 men are employed attending to the trees. The seats in streets and squares number 300.

Sewage.—We visited the great sewer in the Rue de la Pépinière, being met there by the officers of the municipality, detailed by order of M. Bufflers. This sewer was lighted up by means of fifty-six moderator lamps. The man in attendance showed the apparatus for pushing along sand and mud deposited on the bottom of the sewer. The sewer first inspected was of the second class. The water pipes and gas pipes are attached to the crown or sides of the sewers, thus avoiding tearing up the roadway when pipes need repairing. A truck, with paddle board moved by the

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current, is used to force along the sand and mud. We next visited the main sewer, or collector of all sewage coming from the right bank of the Seine. The mean velocity in the collector was 165 feet per minute. The sewers receive (1) large portions of street sweepings; (2) storm water; (3) water thrown out from houses; (4) contents of water closets; (5) urine from closets fitted with double cylinder. From 500 to 600 men are employed in the sewers, of whom 32 work in the great collector. The length of this main sewer is 7½ miles, the length of main on the left bank of river is 5 miles, and the total length of sewers in the city is 500 miles. The daily outfall of all sewers is 300,000 cubic meters, or 66,000,000 gallons.

Cesspools.—Of these there are still in Paris about 240,000. In the new districts the double cylinder is used; the inner cylinder is pierced with holes to allow of the escape of liquid matter into the outer cylinder, and thence to the sewer. The solid matter is carried away in closed carts and dried at Bondy, and sold for manure. It retains but one-eighth of the nitrogenous elements, and is of little value as manure. The company that undertakes this work receives a yearly grant in aid.

Sewage Farms at Gennevilliers.—We visited the works at Asnieres, five miles below the city, being met by MM. Buffiers and Durand-Claye. A centrifugal pump, worked by a 400 horse-power Corliss engine, lifts in a day about 13,200,000 gallons of sewage (one-fifth of the total amount) to a height of 39 feet, into pipes which carry it across the Seine to the formerly arid chalky plain of Gennevilliers (a distance of about 6,600 feet) for distribution by means of open channels over the fields and gardens. The tube is 3 ft. 7 in. in diameter. The supply ceases when desired by the farmers. Besides this amount there are about 8,500,000 gallons daily received on another part of this plain from St. Ouen, from which it flows without pumping. The remainder of the city sewage is thrown direct into the Seine, causing a horrible stench for miles. The present pumping works have cost £120,000; the proposed further expenditure is £400,000. These works have been seven years in operation; the value of the land on the plain has increased on an average 450 per cent., and in one case 4,000 per cent., or a forty-fold increase. The plain contains 3,000 acres, of which 1,075 are treated with sewage. The main pipes are of beton, varying from 2 ft. to 4 ft. diameter; the smaller are of Doulton's glazed earthenware. Nine miles further from the city is a suitable tract of land, near St. Germains, with an area of 3,750 acres, and the city is in treaty with the State for its permanent acquisition. If successful, it is intended to turn all the sewage on to these two plains. We saw on the sewage farm all kinds of flowers, fruit, vegetables and trees suitable to the climate; the crops appeared healthy and abundant; the water that had passed through the soil seemed quite clean, and was tasteless. The drain pipes for collecting this filtered water are 6,600 ft. in length, the upper half, 3,300 ft., having holes; the lower part next the outfall being quite closed. The results of experiment so far, in yield, per acre, are: Artichokes, 20,000 to 30,000 heads; califlowers, 12,000 heads, weighing 16 tons; carrots, 32 to 52 tons; celery, over 40 tons; cabbage, 56 tons; onions, 24 to 32 tons; potatoes, 12 to 16 tons; pumpkins, 48 to 56 tons. About 10,000 cabbages are planted to the acre, and of these about two-thirds succeed. More than a million heads of cabbages are taken from the plain every year, each weighing on the average 11 lbs., or in all nearly 5,000 tons. It was stated that there was no bad taste or smell in the plants so long as only the roots were in contact with the sewage, and that the plants best suited to sewage treatment are green succulent ones. Young trees thrive remarkably well. The experiment has shown that trees well nourished when young thrive best ultimately, even if removed to a poorer soil. To trees the sewage supply must be stopped at the end of the summer. Mint and other plants, are cultivated for perfumes and for flavoring, and succeed remarkably well. Experiments extended over nine years show that on such soil as the plain of Gennevilliers, about 3,960,000 per acre per annum is the quantity that can be most effectively utilized. At this rate about 5,500 acres would suffice for the sewage of the city with its 2,000,000 of people. The sewage is now given gratis,

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but it is proposed to make a small charge to prevent abuses. A Commission of Inquiry has just reported, and its conclusions may be summarized: (1) Green plants, cabbage, celery, lettuce, root crops, and "industrial plants," such as mint, are those best adapted to sewage treatment. (2) That the distribution of the sewage should be by open furrows, as at Gennevilliers. (3) That the supply should be intermittent and frequent. (4) That sewage be not allowed to touch any part of the plant except the root. (5) That the place of the furrows should be frequently changed.

THE RELATION BETWEEN ELECTRICITY AND LIGHT.*

From "Nature."

EVER since the subject on which I have the honor to speak to you to-night has arranged, I have been astonished at my own audacity in proposing to deal in the course of sixty minutes with a subject so gigantic and so profound, that a course of sixty lectures would be quite inadequate for its thorough and exhaustive treatment.

I must, indeed, confine myself carefully to some few of the typical and most salient points in the relation between electricity and light, and I must economize time by plunging at once into the middle of the matter without further preliminaries.

Now, when a person is setting off to discuss the relation between electricity and light, it is very natural and very proper to pull him up short with the two questions: What do you mean by electricity? and, What do you mean by light? These two questions I intend to try briefly to answer. And here let me observe that in answering these fundamental questions I do not necessarily assume a fundamental ignorance on your part of these two agents, but rather the contrary; and must beg you to remember that if I repeat well-known and simple experiments before you, it is for the purpose of directing attention to their real meaning and significance, not to their obvious and superficial characteristics; in the same way that I might repeat the exceedingly familiar experiment of dropping a stone to the earth if we were going to define what we meant by gravitation.

Now, then, we will ask first, what is electricity? and the simple answer must be, we don't know. Well, but this need not, necessarily, be depressing. If the same question were asked about matter, or about energy, we should have likewise to reply, no one knows.

But then the term matter is a very general one, and so is the term energy. They are heads, in fact, under which we classify more special phenomena.

Thus, if we were asked what is sulphur, or what is selenium, we should at least be able to reply, a form of matter; and then proceed to describe its properties, *i. e.*, how it affected our bodies and other bodies.

Again, to the question, what is heat? we can reply, a form of energy; and proceed to describe the peculiarities which distinguish it from other forms of energy.

But to the question, what is electricity? we have no answer pat like this. We cannot assert that it is a form of matter, neither can we deny it; on the other hand we certainly cannot assert that it is a form of energy, and I should be disposed to deny it; it may be that electricity is an entity *per se*, just as matter is an entity *per se*.

Nevertheless, I can tell you what I mean by electricity by appealing to its known behavior.

Here is a battery, that is, an electricity pump; it will drive electricity along. Prof. Ayrton is going, I am afraid, to tell you, on the 20th of January next, that it *produces* electricity; but if he does, I hope you will remember that that is exactly what neither it nor anything else can do. It is as impossible to generate electricity in the sense I am trying to give the word, as it is to produce matter. Of course I need hardly say that

* A lecture by Dr. O. J. Lodge, delivered at the London Institution, on December 16, 1880.

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Prof. Aryton knows this perfectly well; it is merely a question of words, *i. e.*, of what you understand by the word electricity.

I want you, then, to regard this battery and all electrical machines and batteries as kinds of electricity pumps, which drive the electricity along through the wire very much as a water pump can drive water along pipes. While this is going on the wire manifests a whole series of properties, which are called the properties of the current.

[Here were shown an ignited platinum wire, the electric arc between to carbons, an electric machine spark, an induction coil spark, and a vacuum tube glow. Also a large nail was magnetized by being wrapped in the current, and two helices were suspended and seen to direct and attract each other.]

To make a magnet, then, we only need a current of electricity flowing round and round in a whirl. A vortex or whirlpool of electricity is, in fact, a magnet; and *vice versa*. And these whirls have the power of directing and attracting other previously existing whirls according to certain laws, called the laws of magnetism. And, moreover, they have the power of exciting fresh whirls in neighboring conductors, and of repelling them according to the laws of diamagnetism. The theory of the actions is known; though the nature of the whirls, as of the simple stream of electricity, is at present unknown.

[Here was shown a large electro-magnet and an induction-coil vacuum discharge spinning round and round when placed in its field.]

So much for what happens when electricity is made to travel along conductors, *i. e.*, when it travels along like a stream of water in a pipe, or spins round and round like a whirlpool.

But there is another set of phenomena, usually regarded as distinct, and of another order, but which are not so distinct as they appear, which manifest themselves when you join the pump to a piece of glass or any non-conductor, and try to force the electricity through that. You succeed in driving some through, but the flow is no longer like that of water in an open pipe; it is as if the pipe were completely obstructed by a number of elastic partitions or diaphragms. The water cannot move without straining and bending these diaphragms, and if you allow it, these strained partitions will recover themselves and drive the water back again. [Here was explained the process of charging a Leyden jar.] The essential thing to remember is that we may have electrical energy in two forms, the static and the kinetic; and it is, therefore, also possible to have the rapid alternation from one of these forms to the other, called vibration.

Now we will pass to the second question: What do you mean by light? And the first and obvious answer is, everybody knows. And everybody that is not blind does know to a certain extent. We have a special sense-organ for appreciating light, whereas we have none for electricity. Nevertheless, we must admit that we really know very little about the intimate nature of light—very little more than about electricity. But we do know this, that light is a form of energy; and, morever, that it is energy rapidly alternating between the static and the kinetic forms—that it is, in fact, a special kind of energy of vibration. We are absolutely certain that light is a periodic disturbance in some medium, periodic both in space and time; that is to say, the same appearances regularly recur at certain equal intervals of distance at the same time, and also present themselves at equal intervals of time at the same place; that in fact it belongs to the class of motions called by mathematicians undulatory or wave motions. The wave motion in this model (Powell's wave apparatus) results from the simple up-and-down motion popularly associated with the term *wave*. But when a mathematician calls a thing a wave he means that the disturbance is represented by a certain general type of formula, not that it is an up-and-down motion, or that it looks at all like those things on the top of the sea. The motion of the surface of the sea falls within that formula, and hence is a special variety of wave motion, and the term wave has acquired in popular use this signification and nothing else. So that when one speaks ordinarily of a wave or undulatory motion one immediately thinks of something heaving up and down, or even perhaps of something breaking on the shore. But

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when we assert that the form of energy called light is *undulatory*, we by no means intend to assert that anything whatever is moving up and down, or that the motion, if we could see it, would be anything at all like what we are accustomed to in the ocean. The kind of motion is unknown; we are not even sure that there is anything like motion in the ordinary sense of the word at all.

Now, how much connection between electricity and light have we perceived in this glance into their natures? Not much, truly. It amounts to about this: That on the one hand electrical energy may exist in either of two forms—the static form, when insulators are electrically strained by having had electricity driven partially through them (as in the Leyden jar), which strain is a form of energy because of the tendency to discharge and do work; and the kinetic form, where electricity is moving bodily along through conductors or whirling round and round inside them, which motion of electricity is a form of energy, because the conductors and whirls can attract or repel each other and thereby do work.

And, on the other hand, that light is the rapid alternation of energy from one of these forms to the other—the static form where the medium is strained, to the kinetic form when it moves. It is just conceivable, then, that the static form of the energy of light is *electro*-static, that is, that the medium is *electrically* strained, and that the kinetic form of the energy of light is *electro*-kinetic, that is, that the motion is not ordinary motion, but electrical motion—in fact that light is an electrical vibration, not a material one.

On November 5th, last year, there died at Cambridge a man in the full vigor of his faculties—such faculties as do not appear many times in a century—whose chief work has been the establishment of this very fact, the discovery of the link connecting light and electricity; and the proof—for I believe it amounts to a proof—that they are different manifestations of one and the same class of phenomena—that light is, in fact, an electro-magnetic disturbance. The premature death of James Clerk Maxwell is a loss to science, which appears at present, utterly irreparable, for he was engaged in researches that no other man can hope as yet adequately to grasp and follow out: but, fortunately, did not occur till he had published his book on "Electricity and Magnetism," one of those immortal productions which exalt one's idea of the mind of man, and which has been mentioned by competent critics in the same breath has the "Principia" itself.

But it is not perfect like the "Principia;" much of it is rough hewn, and requires to be thoroughly worked out. It contains numerous misprints and errata, and part of the second volume is so difficult as to be almost unintelligible. Some, in fact, consist of notes written for private use, and not intended for publication. It seems next to impossible now to mature a work silently for twenty or thirty years, as was done by Newton two and a half centuries ago. But a second edition was preparing, and much might have been improved in form if life had been spared to the illustrious author.

The main proof of the electro magnetic theory of light is this. The rate at which light travels has been measured many times, and is pretty well known. The rate at which an electromagnetic wave disturbance would travel if such could be generated (and Mr. Fitzgerald of Dublin thinks he has proved that it cannot be generated directly by any known electrical means) can be also determined by calculation from electrical measurements. The two velocities agree exactly. This is the great physical constant known as the ratio V, which so many physicists have been measuring, and are likely to be measuring for some time to come.

Many and brilliant as were Maxwell's discoveries, not only in electricity, but also in the theory of the nature of gases, and in molecular science generally, I can not help thinking that if one of them is more striking and more full of future significance than the rest, it is the one I have just mentioned—the theory that light is an electrical phenomenon.

The first glimpse of this splendid generalization was caught in 1845, five-and-thirty years ago, by that prince of pure experimentalists, Michael Faraday. His reasons for suspecting some connection between electricity and light are not

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clear to us—in fact, they could not have been clear to him; but he seems to have felt a conviction that if he only tried long enough, and sent all kinds of rays of light in all possible directions across electric and magnetic fields in all sorts of media, he must ultimately hit upon something. Well, this is very nearly what he did. With a sublime patience and perseverance which remind one of the way Kepler hunted down guess after guess in a different field of research, Faraday combined electricity, or magnetism, and light in all manner of ways, and at last he was rewarded with a result. And a most out-of-the-way result it seemed. First, you have got to get a most powerful magnet and very strongly excite it; then you have to pierce its two poles with holes, in order that a beam of light may travel from one to the other along the lines of force; then, as ordinary light is no good, you must get a beam of plane polarized light and send it between the poles. But still no result is obtained until, finally, you interpose a piece of a rare and out-of-the-way material which Faraday had himself discovered and made, a kind of glass which contains borate of lead, and which is very heavy, or dense, and which must be perfectly annealed.

And now, when all these arrangements are completed, what is seen is simply this, that if an analyzer is arranged to stop the light and make the field quite dark before the magnet is excited, then—directly the battery is connected and the magnet called into action—a faint and barely perceptible brightening of the field occurs; which will disappear if the analyzer be slightly rotated. [The experiment was then shown.] Now, no wonder that no one understood this result. Faraday himself did not understand it at all; he seems to have thought that the magnetic lines of force were rendered luminous, or that the light was magnetized—in fact, he was in a fog, and had no idea of its real significance. Nor had any one. Continental philosophers experienced some difficulty and several failures before they were able to repeat the experiment. It was, in fact, discovered too soon, and before the scientific world was ready to receive it, and it was reserved for Sir William Thomson briefly, but very clearly, to point out, and for Clerk Maxwell more fully to develop, its most important consequences. [The principle of the experiment was then illustrated by the aid of a mechanical model.]

This is the fundamental experiment on which Clerk Maxwell's theory of light is based; but of late years many fresh facts and relations between electricity and light have been discovered, and at the present time they are tumbling in in great numbers.

It was found by Faraday that many other transparent media besides heavy glass would show the phenomenon if placed between the poles, only in a less degree; and the very important observation that air itself exhibits the same phenomenon, though to an exceedingly small extent, has just been made by Kundt Röntgen in Germany.

Dr. Kerr, of Glasgow, has extended the result to opaque bodies, and has shown that if light be passed through magnetized *iron* its plane is rotated. The film of iron must be exceedingly thin, because of its opacity, and hence, though the intrinsic rotating power of iron is undoubtedly very great, the observed rotation is exceedingly small and difficult to observe; and it is only by very remarkable patience and care and ingenuity that Dr. Kerr has obtained his result. Mr. Fitzgerald, of Dublin, has examined the question mathematically, and has shown that Maxwell's theory would have enabled Dr. Kerr's result to be predicted.

Another requirement of the theory is, that bodies which are transparent to light must be insulators or non-conductors of electricity, and that conductors of electricity are necessarily opaque to light. Simple observation amply confirms this; metals are the best conductors, and are the most opaque bodies known. Insulators, such as glass and crystals, are transparent whenever they are sufficiently homogeneous, and the very remarkable researches of Prof. Graham Bell in the last few months have shown that even *ebonite*, one of the most opaque insulators to ordinary vision, is certainly transparent to some kinds of radiation, and transparent to no small degree.

[The reason why transparent bodies must insulate, and why conductors must

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be opaque, was here illustrated by mechanical models.]

A further consequence of the theory is that the velocity of light in a transparent medium will be affected by its electrical strain constant; in other words, that its refractive index will bear some close but not yet quite ascertained relation to its specific inductive capacity. Experiment has partially confirmed this, but the confirmation is as yet very incomplete. But there are a number of results not predicted by theory, and whose connection with the theory is not clearly made out. We have the fact that light falling on the platinum electrode of a voltameter generates a current, first observed, I think, by Sir W. R. Grove—at any rate it is mentioned in his "Correlation of Forces"—extended by Becquerel and Robert Sabine to other substances, and now being extended to fluorescent and other bodies by Prof. Minchin. And finally—for I must be brief—we have the remarkable action of light on selenium. This fact was discovered accidentally by an assistant in the laboratory of Mr. Willoughby Smith, who noticed that a piece of selenium conducted electricity very much better when light was falling upon it than when it was in the dark. The light of a candle is sufficient, and instantaneously brings down the resistance to something like one-fifth of its original value.

I could show you these effects, but there is not much to see; it is an intensely interesting phenomenon, but its external manifestation is not striking—any more than Faraday's heavy glass experiment was.

This is the phenomenon which, as you know, has been utilized by Prof. Graham Bell in that most ingenious and striking invention, the photophone. By the kindness of Prof. Silvanus Thompson I have a few slides to show the principle of the invention, and Mr. Shelford Bidwell has been good enough to lend me his home-made photophone, which answers exceedingly well for short distances.

I have now trespassed long enough upon your patience, but I must just allude to what may very likely be the next striking popular discovery, and that is the transmission of light by electricity; I mean the transmission of such things as views and pictures by means of the electric wire. It has not yet been done, but it seems already theoretically possible, and it may very soon be practically possible.

SCIENCE TEACHING IN THE PUBLIC SCHOOLS.

From the Proceedings of the American Association for the Advancement of Science.*

REPORT OF COMMITTEE ON SCIENCE TEACHING IN THE PUBLIC SCHOOLS:

THE Committee appointed at the Saratoga meeting of the American Association on Science Teaching in the Public Schools, respectfully submit the preliminary Report.

The repeated appointment by this body, in successive years, of committees to look into the scientific education of the public schools, must be taken as showing that such an inquiry is regarded as both legitimate and important. Yet the duties of such a committee have not been defined by the Association, nor have any of our predecessors opened the way to a consideration of the subject. It was probably expected that we would furnish a digest of information from many quarters, as to what sciences are taught in the public schools, with what facilities, and to what extent; accompanied by such recommendations regarding the increase of scientific studies as the results might suggest. But our course has not proved to be so clear. We have been arrested at the outset by a question of the quality of the science teaching in these schools which demands the first consideration. There are certain radical deficiencies in current science teaching, the nature and extent of which must be understood before any measures of practical improvement can be intelligently taken up. We shall here confine ourselves to this preliminary inquiry.

* The report of the Committee on Science Teaching in the Public Schools. The Committee consisted of R. L. Youmans, A. R. Grote, J. W. Powell, N. S. Shaler and J. S. Newbery.

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The investigations has interest from the immense extent, and rapidly increasing influence, of the American public schools. There are now nearly one hundred and fifty thousand of these schools, supported at an annual expense of probably seventy or eighty million dollars. Maintained by state authority, they are firmly established in the respect and confidence of the community. Under the influence of normal schools, teachers' institutes, systematic superintendence, school boards, regulative legislation, and an extensive literature devoted specially to education, they have become organized into a system which is gradually growing settled and unified in its methods. With unbounded means and unlimited authority, these schools have undertaken to form the mental habits of the great mass of the youth of this country. They prescribe the subjects of study, the modes of study, and the extent and duration of studies for all the pupils that come under their charge. The sphere of their operations is, moreover, steadily extending. They are everywhere encroaching upon the province of higher education, everywhere trenching upon private schools and diminishing the interest in home education.

It may be assumed that the time has fully come when this system must be measured by the standards of science, and approved or condemned by the degree of its conformity to what these standards require. Science has become in modern times the great agency of human amelioration, the triumphs of which are seen on every hand and felt in all experience. Grave subjects are brought successively under its renovating and reconstructive influence; and latest and most important among them is the subject of education. Our inquiry now is, how far the public-school system has availed itself of the valuable aid that science offers in the proper cultivation of the minds of the young.

The interest and necessity of such an investigation will hardly be denied; but there may be a query as to its relevancy to the appropriate work of this society. The making of science popular was not among the objects for which our association was formed. Not that its founders were unmindful of the importance of widely diffusing the results of research; but they recognized that the interests of science are so vast, as to be only efficiently promoted by division of labor. Under the operation of this principle it was made the distinctive purpose of the association to contribute to the extension of original science by the discovery of new scientific truth, leaving its dissemination to the schools, the press, and the various agencies of public enlightenment. Nor does your committee understand that it is now proposed to depart from this policy; for the inquiry before us is really most pertinent to our special objects. It certainly cannot be a matter of indifference to this body, from its own point of view, how science is dealt with in the great system of schools which has undertaken the task of moulding the youthful mind of the country. We aim to advance science by the promotion of original investigation, which depends upon men prepared for the work. Do the schools of the nation, by their modes of scientific study, favor or hinder this object? Do they foster the early mental tendencies that lead to original thought; or do they thwart and repress them? We have an undoubted concern in this matter, and it is, moreover, strictly identical with that of the community at large; for there can be no better test than this of the real character of a school system. When we ask whether a mode of teaching and a manner of study are calculated to awaken the spirit of inquiry, to cultivate the habit of investigation, and rouse independent thought, our question goes to the root of all true education.

All sciences are the products of a method of thinking, and it is that method which concerns us when we propose to regard it as a means of mental cultivation. Science is an outgrowth of common knowledge, and the scientific method is but a development of the ordinary processes of thought that are employed by everybody. The common knowledge of people is imperfect because their observations are vague and loose, their reasoning hasty and careless, their minds warped by prejudice and deadened by credulity, and because they find it easier to invent fanciful explanations of things than to discover the real ones. For thousands of years the knowledge of nature

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was rude and stationary because the habits of thought were so defective. But with a growing desire to understand how the world around is constituted, men improved their processes of thinking. They began, and were compelled to begin, by questioning accepted facts, and doubting current theories. The first step was one of self-assertion, implying that degree of mental independence which led men to think for themselves. They learned to make their own observations and to trust them against authority. It was found, as a first and indispensable condition of gaining clear ideas, that the mind must be occupied directly with the subject to be investigated. In this way scientific inquiry at length grew into a method of forming judgments which was characterized by the most vigilant and disciplined precautions against error. Of the mental processes involved in research it is unnecessary here to speak; we are only concerned to know that the scientific method is simply a systematic exercise in truth-seeking, and is the only mode of using the human mind when it is desired to attain the most accurate and perfect form of knowledge. The whole body of modern scientific truth, disclosing the order of nature and guiding the development of civilization, must be taken as an attestation of the validity of the scientific method of thought by which these results have been established. We here get rid of all cramping limitations. The scientific method is applicable to all subjects whatever that involve constancy of relations, causes and effects, and conform to the operation of law. It is applicable wherever evidence is to be weighed, error got rid of, facts determined, and principles established. Our public schools, unhappily, make but little use of this method in the work of mental cultivation, and we shall find some explanation of this by referring to the way they grew up.

The American public school system originated in the theory that the State owes to every child the rudiments of a common education, or an elementary knowledge of reading, writing and arithmetic, as implements of after mental improvement. But it was early found difficult to separate the primary use of tools from the acquisition of knowledge. Mr. Everett said: "I will thank any person to show why it is expedient and beneficial in the community to make public provision for teaching the elements of learning, and not expedient or beneficial to make similar provision to aid the learner's progress toward the mastery of the most difficult branches of science and the choicest refinements of literature." Under the influence of such considerations the rudimentary studies rapidly developed into sources of study embracing a variety of subjects. This led to the systematizing of instruction and the grading of schools, so that in nearly all the towns of the United States the public schools have been divided into primaries for the younger pupils and the grammar schools for older pupils; while within twenty-five years a third grade has arisen known as the high schools for the most advaneed students. In each division there are subgrades, and wherever improvements in public-school education are attempted, the principle of gradation is fundamental. So essential is it considered, that no aid is granted from the Peabody fund except to graded schools. As regards the plan of studies adopted there was no guiding principle. All sorts of subjects, and these for all sorts of reasons were taken up, and among them the sciences which are now regular parts of public school duty. Classes are found in physics, chemistry, mineralogy, geology, physiology, botany and zoology. There are text-books upon all these branches, graded to the varying capacities of learners. Teachers prepare in them, and in many cases apparatus is provided, and there are lectures with experiments, spe specimens, maps and charts for illustrations.

The old ideal of a school is a place where knowledge is got from books by the help of teachers, and our public school system grew up in conformity with this ideal. The early effect of grading was to fix and consolidate imperfect methods. The sciences were assimilated to the old practice, and the science teaching falls short at just the points where it was inevitable that it should fall short. The methods of school teaching, and the habits of the teachers, had grown rigid under the *regime* of book-studies. As a consequence the science teaching in the public schools is

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generally carried on by *instruction*. Through books and teachers the pupil is filled up with information in regard to science. Its facts and principles are explained as far as possible, and then left in the memory with his other school acquisitions. He learns the sciences much as he learns geography and history. Only in a few exceptional schools is he put to any direct mental work upon the subject-matter of science, or taught to think for himself.

As thus treated the sciences have but value in education. They fall below other studies as means of mental cultivation. Arithmetic arouses mental reaction. The rational study of language, by analytical and constructive tasks and the mastery of principles, strengthens the mental processes; but the sciences are not employed to train the faculties in the various ways to which they are severally adapted. They are not made the means of cultivating the observing powers, stimulating inquiry, exercising the judgment in weighing evidence, nor of forming original and independent habits of thought. The pupil does not know the subjects he professes to study by actual acquaintance with the facts, and he therefore becomes a mere passive accumulator of second-hand statements. But it is the first requirement of the scientific method, alike in education and in research, that the mind shall exercise its activity directly upon the subject matter of study. Otherwise scientific knowledge is an illusion and a cheat. As science is commonly pursued in book descriptions the learners cannot even identify the things they read about. As remarked by Agassiz, "the pupil studies Nature in the school-room, and when he goes out of doors he cannot find her." This mode of teaching science, which is by no means confined to the public schools, has been condemned in the most unsparing manner by all eminent scientific men as a "deception," a "fraud," an "outrage upon the minds of the young," and "an imposture in education."

Nor has this criticism of bad practices been without its effect. We are met by the statement that much has been done in the public schools to escape the evils of mere book science. The method of object lessons has been extensively introduced into primary schools with the professed purpose of cultivating the powers of observation in childhood. It is claimed that this is a beginning in science; and, as it brings the mind into action upon things, is a corrective of the inordinate study of words. But object teaching has not yielded what was expected of it; and is in no true sense a first step in science. Nothing is gained educationally by barely having an object in hand when it is talked about. Myriads of objects are present to the senses of people but no insight follows. The observing faculties must be tasked if they are to be trained. The pupil is not to have the properties of objects pointed out, but he is to find them out. Science will do its work of educating the observing faculties only as they are quickened and sharpened by exercise in discrimination. The scientific aim is to replace vague confused impressions by clear and accurate ideas. Skill in the detection of nice distinctions is only gained by prolonged and careful practice. Object lessons afford no such cultivation. We do not say they are useless, but they are not the A B C of science, and do not, as a matter of fact, open the way to the proper study of the special sciences. This is their test and their condemnation. When the primary pupils have gone over their prescribed course of object lessons, and are passed on to a higher grade, strange to say the "objects" are suddenly dropped as if the objective method had been exhausted. In the technical phrase *perceptive* education is to be replaced by *conceptive* education. Instruction in elementary science is now to be carried on by what is known as oral teaching. This method as extensively practised in the grammar grades of the public schools is everywhere growing in favor, and we are once more told that it is a successful revolt against book studies. It is chiefly applicable to the sciences and its cardinal idea is instruction without a text book. This looks fair but it is delusive. The method does not remove the book that the pupil may come at the phenomena, but it removes the book that the teacher may take its place. Oral teaching is class instruction, in which information is imparted in a familiar manner with the view of awakening the interest of the class. But so far as real science is concerned it is doubtful if this method

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is not worse than the one it replaces. Following the maxim of certain German educators that "the teacher is the school," it was assumed that when apathy prevails in the school room it is solely the teacher's fault. Oral exercises enable them to escape this reproach by giving animation to school work. It is said that this is a "live system" in contrast to the old humdrum routine of lessons and recitations. But science gets no real help. There is only the substitution of a superficial class activity for the more deliberate work of the individual pupil. More mental effort is required on his part to get a lesson from a book than to listen to a lesson given by the teacher. The teacher is to do everything, and stands in the place not only of the book but of the pupil also. Is this not a step backward in education? The teacher is magnified at the expense of close study, and science is cheapened by the method. Oral teaching implies a fertility, a versatility, and a proficiency in scientific knowledge on the part of teachers which that class of persons does not possess. It is a premium on tutorial smattering and cramming by which the voluble teacher with superficial acquisitions and a ready memory becomes the 'model teacher. There may be benefits in this method, but science does not gain them. Judicious oral assistance, as in the physical, chemical, or natural history laboratory, given by a competent master to a pupil at work, is invaluable for stimulus and guidance; but the aid must be discreet and the skillful teacher will not talk too much. But where it is all talk and no work, and text books are filtered through the very imperfect medium of the ordinary teacher's mind, and the pupil has nothing to do but to be instructed, every sound principle of education is outraged, and science is only made ridiculous.

This failure to gain the benefits of real scientific study has its source deep in the constitution of the public schools. In dealing with masses of children, classification became necessary which gave rise, as we have seen, to grading and an elaborate mechanical system. The working of children in lots seems to be a necessity of the public schools, but it strengthens the practice of verbal instruction recitations and lesson giving. It is well fitted to impress the public with the idea that there is much done in the schools. There is a prescribed routine of operations and a display of order that is admired. But teacher and learner are subordinated to the system. It is machine work and machines make no allowances. Gradation assumes and enforces a uniformity among pupils which is not according to the facts. Wide personal differences of capacity, aptitude, attainment and opportunity, not only exist among children, but they are the prime data of all efficient mental cultivation. In the graded schools, just in proportion to the perfection of the mechanical arrangements, individuality disappears. Special original capacity, the main thing, counts for nothing. The mind cannot be trained in such circumstances to originate its own judgments. The exercise of original mental power or independent inquiry is the very essence of the scientific method and with this the practice of the public schools is at war. Moreover, a system which deals with the average mind and does not get at the individual mind breaks down at the point where all true education really begins, that is, in promoting self-culture. The value of educational systems consists simply in what they do to incite the pupil to help himself. Mechanical school work can give instruction, but it cannot develop faculty, because this depends upon self-exertion. Science, if rightly pursued, is the most valuable school of self-instruction. From the beginning men of science have been self-independent and self-reliant because self-taught; and it is a question whether they have been most hindered or helped by the schools. De Candolle, in his valuable book on the conditions which favor the production of scientific men, says that the discoverers, the masters of scientific method have chiefly appeared in small towns where educational resources have been scanty; and that they have often been most helped by the very poorness of their teaching which threw them back upon themselves. It was to their advantage that the schools were not so perfect as to extinguish individuality and thus destroy originality.

Our strictures are here upon the general working of the public school system; but we recognize that there are many exceptional teachers who do what

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they can to deal with science in the true spirit, while multitudes of instructors are chafing under present restrictions and groping after something better. The bad system is moreover continued chiefly from the lack of knowledge as to the possibilities of a better. But the better method of teaching science has been proved entirely practicable. The institution where we meet and many other science schools have shown it. A large number of teachers have demonstrated that various branches of science can be taught to the young by the true as well as by the false method. What is now most urgently needed is to gather from these experiences practical plans of improvement in science teaching for the benefit of those who desire better guidance than they now have.

In his address as Rector of the University of Aberdeen, Professor Huxley said: "I would not raise a finger to introduce more book work into every art curriculum in the country." We concur in this view as applied to the present science teaching in our public schools. We would not raise a finger to extend it. President Barnard, of Columbia College, in a public address reprobating in severe terms the common method of teaching science as being an inversion of the true order of cultivating the mental faculties, referred to the great benefits which must arise "when our systems of education shall have been remodeled from top to bottom." That result may come about in the fulness of time, but it is wise to expect only a slow and gradual improvement. Vice-President Grote, in his St. Louis address, pointed out the guiding principle in this case as a substitution of real knowledge for second-hand information by a necessary law of mental advancement. In obedience to this principle, the cultivators of original science should do what they may to raise the standard of our prevalent science teaching; and we respectfully ask that the Association will assign to a committee the duty of reporting at our next meeting on the best modes of improving the teaching of science in our public schools.

ON DUST, FOGS, AND CLOUDS.*

By JOHN AITKEN.

From "Nature."

DUST, fogs, and clouds seem to have but little connection with each other, and we might think they could be better treated of under two separate and distinct heads. Yet I think we shall presently see that they are more closely related than might at first sight appear, and that dust is the germ of which fogs and clouds are the developed phenomena.

This was illustrated by an experiment in which steam was mixed with air in two large glass receivers; the one receiver was filled with common air, the other with air which had been carefully passed through a cotton-wool filter and all the dust removed from it. In the unfiltered air the steam gave the usual and well-known cloudy form of condensation, while in the filtered air no cloudiness whatever appeared. The air remained supersaturated and perfectly transparent.

The difference in the behavior of the steam in these two cases was explained by corresponding phenomena, in freezing, melting, and boiling. It was shown that particles of water vapor do not combine with each other to form a cloud particle, but the vapor must have some solid or liquid body on which to condense. Vapor in pure air therefore remains uncondensed or super-saturated, while dust particles in ordinary air form the nuclei on which the vapor condenses and forms fog or cloud particles.

This represents an extremely dusty condition of the air, as every fog and cloud particle was formerly represented by a dust particle, which vapor by condensing upon it has made visible. When there is much dust in the air but little vapor condenses on each particle,

* Abstract of a paper read to the Royal Society of Edinburgh.

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and they become but little heavier, and easily float in the air. If there are few dust specks each gets more vapor, is heavier, and falls more quickly.

These experiments were repeated with an air-pump, a little water being placed in the receiver to saturate the air. The air was then cooled by slightly reducing the pressure. When this is done with unfiltered air a dense cloudiness fills the receiver, but when with pure air no fogging whatever takes place, there being no nuclei on which the condensation can take place. In this experiment, and in the one with steam, the number of cloud particles is always in proportion to the dust present. When the air is nearly pure and only a few dust particles present, then only a few cloud particles form, and they are heavy and fall like fine rain.

The conclusions drawn from these experiments are: (1) that whenever water vapor condenses in the atmosphere it always does so on some solid nucleus; (2) that dust particles in the air form the nuclei on which the vapor condenses; (3) that if there was no dust there would be no fogs, no clouds, no mists, and probably no rain, and that the supersaturated air would convert every object on the surface of the earth into a condenser on which it would deposit; (4) our breath when it becomes visible on a cold morning, and every puff of steam as it escapes into the air, show the impure and dusty condition of our atmosphere.

The source of the fine atmospheric dust was then referred to, and it was shown that anything that broke up matter into minute parts would contribute a share. The spray from the ocean, when dried and converted into fine dust, was shown to be an important source. Meteoric matter also probably contributed a proportion. Attention was then directed to the power of heat and combustion as a source of this fine dust.

It was shown that if there is much dust then each particle only gets a little vapor condensed upon it, that when the particles are numerous they become but little heavier, and easily float in the air, and give rise to that close packed but light form of condensation which constitutes a fog, and therefore whatever increases the amount of dust in the air tends to increase fogs, and that when the dust particles are not so numerous the cloud particles are larger and settle down more quickly.

It was shown that by simply heating any substance, such as a piece of glass, iron, brass, &c., a cloud of dust was driven off, which, when carried along with pure air into the experimental receiver, gave rise to a dense fog when mixed with steam. So delicate is this test for dust that if we heat the one-hundredth of a grain of iron wire the dust driven off from it will give a distinct cloudiness in the experimental receiver, and if we take the wire out of the apparatus and so much as touch it with our fingers and again replace it, it will again be active as a cloud producer. Many different substances were tried, and all were found to be active fog producers. Common salt is perhaps one of the most active.

Heat, it is well known, destroys the motes in the air, and it might be thought that flame and other forms of combustion ought to give rise to a purer air. Such, however, is not the case. Gas was burned in a glass receiver, and supplied with filtered air for combustion, and it was found that the products of combustion of pure air and dustless gas gave rise to an intensely fog-producing atmosphere. It may be mentioned here that the fog-producing air from the heated glass, metals, and burning gas were each passed through the cotton-wool filter, and the air was in all cases made pure, and did not give rise to cloudiness when mixed with steam.

It will be seen that it is not the dust motes which are revealed to us by a beam of sunlight when shining into a darkened room, that form the nuclei of fog and cloud particles, as these may be entirely removed by heat, and yet the air remain active as a cloud producer. The heat would seem to break up the larger motes which reflect the light into smaller and invisible ones. When speaking of dust, it is to these infinitesimally small and invisible particles we refer. The larger motes which reflect the light will no doubt be active nuclei, but their number is too small to have any important effect.

It is suggested, and certain reasons are given for supposing, that the blue

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color of the sky is due to this fine dust.

Other experiments were made to test the fog-producing power of the air and gases from different sources. The air to be tested was introduced into the experimental receiver and mixed with steam, and the relative densities of the fog produced were noted. It was always found that the air of the laboratory where gas was burning gave a denser fog than the air outside, and that the air outside varied, giving less fog during wet than during dry weather. The products of combustion of gas burned in a Bunsen flame, a bright flame, and a smoky flame, were all tested and found to be about equally bad, and all much worse than the air in which they were burned. Products of combustion from a clear fire and from a smoky one gave about equal fogging, and both much worse than the air of the room.

Experiments were made by burning different substances. Common salt when burned in a fire or in alcohol flame gave an intensely fog-producing atmosphere, but burned sulphur was the most active substance experimented on. It gave rise to a fog so dense it was impossible to see through a thickness of 5 cm. of it.

The vapors of other substances than water were tested to see if they would condense in the cloud form without nuclei on which to deposit. All the substances experimented on, which included sulphuric acid, alcohol, benzole, and paraffin, only gave a cloudy condensation when mixed with ordinary unfiltered air, and remained perfectly clear when mixed with filtered air, all these acting like water vapor.

Before referring to fogs, which have now become so frequent and aggravated in our large towns, it was pointed out that caution was necessary in applying the results of the experiments.

The conditions of a laboratory experiment are so different, and on so small a scale, that it is not safe to carry their teaching to the utmost limits and apply them to the processes which go on in nature. We may, however, look to the experiments for facts from which to reason, and for processes which will enable us to understand the grander workings of nature.

It having been shown that vapor, by condensing on the dust particles in the air, gives rise to a fogging, the density of which depends on the amount of fine dust in the air; the more dust the finer are the fog particles, and the longer they remain suspended in the air. It having been also shown that all forms of combustion, perfect and imperfect, are producers of fog nuclei, it is concluded that it is hopeless to expect that, adopting more perfect forms of combustion than those at present in use, we shall thereby diminish the frequency, persistency, or density of our town fogs. More perfect combustion will, however, remove the pea-soup character from the fogs and make them purer and whiter, by preventing the smoke which at present mixes with our town fogs and aggravates their character, and prevents them dissolving when they enter our rooms. Smoke descends during a fog, because the smoke particles are good radiators, and soon get cooled and form nuclei on which the water vapor condenses. The smoke thus becomes heavier and falls. This explains why falling smoke is often a sign of coming rain. It indicates a saturated condition of the atmosphere.

Sulphur when burned has been shown to be an intensely active fog producer. Calculation shows that there are more than 200 tons of sulphur burned with the coal every winter day in London, a quantity so enormous as quite to account for the density of the London fogs. It is suggested that some restriction ought to be put on the amount of sulphur in the coal used in towns.

Before utterly condemning the smoke and the sulphur, it was pointed out that it would be necessary thoroughly to investigate and fully to consider the value of smoke as a deodorizer, and also the powerful antiseptic properties of the sulphurous acid formed by the burning sulphur. The air during fogs is still and stagnant. There is no current to clear away the foul smells and deadly germs that float in the air, which might be more deadly than they are, were it not for the suspended soot and burned sulphur. We must therefore be on our guard lest we substitute a great and hidden danger for an evident but less evil.

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ON THE CAUSE OF CAVITIES IN CAST STEEL.

By DR. F. C. G. MULLER, of Brandenburg.

Translated from Glaser's Annalen, for Foreign Abstracts of Institution of Civil Engineers.

THE author refers to his researches on the Bessemer process, and on the gas bubbles in Bessemer steel, published in the "Zeitscrift des Vereines deutscher Ingenieure," 1878 and 1879.* The present paper is designed to put his results in a more concise and practical form, and to reply to objections made by certain French metallurgists, especially M. Pourcel.

In the ordinary process of casting steel ingots by running the hot metal into cold ingot moulds, much difficulty is found in obtaining thoroughly sound castings. This arises mainly from two evils, due to entirely different causes; (1) the central funnel-shaped cavity, due to shrinkage of the interior, after the outside is set; (2) dispersed cavities, due to gases imprisoned in the cooling metal. The former always makes the top of the ingot worthless, and sometimes extends far into the interior; but this can be prevented by proper attention in casting, and by special methods. The latter is much more difficult of cure. The fluid metal always holds a considerable quantity of occluded gas, and this, when the metal sets, draws together into small bubbles. In many kinds of steel the ingot boils up during the process of running. Such ingots are to be looked on as sponges filled with gases, and if cut across when cold, are found to present innumerable worm-shaped cavities. If, as is usually done, the boiling is stopped by covering in the ingot with sand, the bubbles are found to be arranged radially in two rows all round the outside of the section, while the central part, and also a skin about half an inch thick, is quite sound. The reason of this phenomenon is that the metal, in splashing down into the mould, loses a part of its occluded gas, and therefore is no longer in a saturated condition. When, therefore, the outside begins to set, the gases first draw into the interior until this becomes saturated, whereupon the formation of bubbles begins, and the mass boils over. The stopping of the mould with sand next causes a severe pressure within the still fluid parts, and the gases are thus kept in solution (or prevented from forming bubbles) even during the process of setting. This pressure is itself a source of danger, as, if the sand is removed too soon an explosion may take place.

These defects are not peculiar to Bessemer steel. They are also found in Siemens-Martin and crucible steel, but intermittently; appearing and disappearing without visible cause. Even if an ingot does not boil, and has an apparently sound head, it may still have cavities here and there in its bulk. It is true that with rolled or forged steel these cavities do not prevent perfectly sound work being produced, though they necessitate greater care, and extra hammering or squeezing, in the subsequent processes. Even rails with honeycombed skins (where the thin outer layer has given way in the furnace, and allowed the cavities to communicate with the air) may give thoroughly good results when tested. But for steel castings such cavities are obviously prejudicial, and for many purposes have altogether prevented their use.

The exact nature of the gases thus occluded has been much discussed, it being generally supposed that they are mainly carbonic oxide. Gautier was the first to treat the point as being settled by experience, and he announced that the soundness of the castings in Terre Noire steel, and also in Krupp's and in the Bochum steel, was due to the presence of silicon, neutralizing the carbonic oxide. This was generally accepted, in spite of the known fact that most of the porous German and Austrian steels were quite as rich in silicon as those above mentioned. The matter was in this condition when the author resolved to test it by direct

*Vide Minutes of Proceedings Inst. C.E., vol. lvi. p. 360; and vol. lx., p. 494.

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experiment.* The experiments showed that the gas consisted, not of carbonic oxide, but of hydrogen mixed with a little nitrogen. This was verified not only for cast steel, but for many different descriptions of iron. Confining the inquiry to steel, two cylinders of Bochum steel, made from the same perfectly sound ingot, but one forged and the other not gave the following results:

	Percentage of gas.	Composition.			
		H.	Ni.	C.	Tot.
Unforged steel	15.5	92.4	5.9	1.4	99.7
Forged steel†..	5.5	73.4	25.3	1.3	100.0

This proves that a certain quantity of gas is occluded among the molecules of the steel, even where there are no visible cavities, and that this gas consists of hydrogen, with about one-fifth of nitrogen. The latter is no doubt derived from the air, and the hydrogen from the moisture contained in the large quantity of air which mixes with the metal, especially in the Bessemer process. The absence of CO is remarkable, because it has been shown by Troost and Hautefeuille that it is readily absorbed by red hot iron, and because it is developed in large quantities in the converter. But with fluid iron it either is not absorbed at all, or in small proportions compared with hydrogen and nitrogen. It may, however, act in another way, namely, by freeing the metal from dissolved gases, in the same way as when water is saturated with an easily soluble gas, and then exposed to a current of gas which will not dissolve in the water, the latter carries away with it a large portion of the former gas. This may explain why samples taken in the middle of the Bessemer process are often quite sound, while those taken towards the end, when the development of CO has ceased, are porous. It also explains the fact that at the Bochum and Hosch (Dortmund) works, absolutely sound Bessemer ingots are obtained by blowing the charge completely dead, and then pouring in 7 per cent. of fluid spiegeleisen. A violent reaction takes place, due to the carbon of the speigeleisen combining with the oxygen of the metal to form CO, and this probably carries off mechanically the hydrogen dissolved in the metal, which would otherwise form cavities in the cold ingot. This was proved by analyzing the gases which escaped, at Bochum, in this final reaction, and which in two cases had the following composition:

	CO.	CO_2	N.	H.	O.	Total.
Analysis No. 1.	82.6	—	14.3	2.8	—	99.70
" No. 2.	78.55	0.86	16.38	2.52	1.32	99.63

It will be seen that hydrogen was present, and in about the proportion demanded by the theory; so that in fact CO is not only innocent of the production of cavities in steel, but may actually be used to prevent them.

Another mode of attaining this end would be by thoroughly drying the air before blowing it through the metals, so as to stop the introduction of hydrogen. This could be done by using burnt lime, with little expense. The nitrogen would, of course, remain, but it is uncertain whether this, by itself, would be harmful.

These discoveries of the author were subsequently criticised by M. Pourcel, who suggested that the hydrogen was due to the ingot having been quenched from a red heat in water; that the water had penetrated into the cavities and decomposed, the oxygen going to oxidize the walls, while the hydrogen remained. This criticism, however, falls to the ground, because the ingots were not quenched as suggested.* In fact this could not have been done without making the steel too hard to bore. Moreover, although red hot steel will decompose steam, there is no reason to suppose that it will decompose cold water; *e.g.*, there is no evidence that hydrogen exists in quenched iron. Nor is it easy to see how hydrogen so formed could have found its way into the interior cavities of the ingot, and certainly not under a pressure of seven atmospheres. It would seem as if the French metallurgists were thinking only of the central cavity, which is open to the atmosphere, and which, of course, was not under consideration at all.

*For the process and results, see Minutes of Proceedings Inst. C.E., vol. lvi., p. 360; and vol. lx., p. 494.

†Mr. E. Windsor Richards has obtained a very similar analysis to this for the gases in steel ingots (Proc. Inst. Mech. Eng. 1880, p. 402).

*In his preliminary report to the German Chemical Society, Dr. Muller mentions that the ingots were cooled in water; it is to be understood, therefore, that this cooling was not begun till their temperature had fallen too low to admit of hardening.

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THE GEOMETRICAL INTERPRETATION OF IMAGINARY QUANTITIES.

Translated from the French of M. Argand by Prof. A. S. HARDY.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

IV.

The treatise, by Argand, appeared in the year 1806.* In Vol. IV., 1813–14, of Gergonne's *Annales de Mathematiques*, appeared an article entitled "New Principles of the Geometry of Position and Geometrical Interpretation of Imaginary Symbols," by J. F. Francais, Professor in the Imperial School of Artillery at Metz, of which the following is an abstract.

The author began by calling attention to the distinction between the magnitude and position of a line, and to the still incomplete state of the geometry of position. He proposed the notation a_α, b_β, ... to represent right lines whose absolute lengths were a, b, the subscript Greek letters denoting the angles made by these lines with any arbitrary axis of reference. Francais used the expression "lines given in magnitude and position," to designate what Argand called "directed right lines." In the term *ratio* he included the relative position as well as the relative magnitude, four directed lines being in proportion as

$$a_\alpha : b_\beta :: c_\gamma : d_\delta,$$

when $\frac{b}{a}=\frac{d}{c}$, and also $\beta-\alpha=\delta-\gamma$. In such a proportion, the absolute lengths are in geometrical, while the angles made with the axis are in arithmetical progression; and the homologous sides of any two similar complanar figures are in proportion. In conformity with the above definition, the proportion

$$a_\alpha : b_\beta :: b_\beta : c_\gamma$$

involves the equations

$$\frac{b}{a}=\frac{c}{b}, \text{ and } \beta-\alpha=\gamma-\beta,$$

whence $\beta=\frac{1}{2}(\alpha+\gamma)$,

or a mean proportional between the directed lines bisects their included angle. So for the continued proportion

$$a_\alpha : b_\beta : c_\gamma \ldots\ldots : l_\lambda : m_\mu,$$

we should have

$$\frac{b}{a}=\frac{c}{b}=\ldots\ldots=\frac{m}{l},$$

and $\beta-\alpha=\gamma-\beta=\mu-\lambda$.

He then proposed a second notation. By the former $a_0=a$, and $1_0=1$; therefore $1 : 1_\alpha :: a : a_\alpha$, or $a_\alpha=a.1_\alpha$; so that a directed line might also be represented by the symbol $a.1_\alpha$, a denoting its length and 1_α its position.

Lines parallel to the axis of reference drawn from left (right) to right (left) were distinguished as positive (negative); angles estimated above (below) the axis from right to left were regarded positive (negative). This convention, in connection with the above notation, gave $+1=1_0$, $-1=1_{\pm\pi}$, and therefore

$$+a=a\times(+1)=a.1_0,$$

and $$-a=a\times(-1)=a.1_{\pm\pi}.$$

And from the known relations

$$+1=e^{0\pi\sqrt{-1}}, \text{ and } -1=e^{\pm\pi\sqrt{-1}},$$

results

$$+a=a\times(+1)=a.e^{0\pi\sqrt{-1}},$$

and $$-a=a\times(-1)=a.e^{\pm\pi\sqrt{-1}}.$$

He then proceeded to establish four theorems:

I. *In the geometry of position, imaginary quantities of the form* $\pm a\sqrt{-1}$ *represent perpendiculars to the axis of reference, and, conversely, perpendiculars to the axis are imaginaries of this form.*

Demonstration.—The quantity $\pm a\sqrt{-1}$ is a mean proportional between $+a$ and $-a$, that is, between a_0 and a_π; hence by the definition of mean proportional is expressed by $a_{\pm\frac{\pi}{2}}$; or, it is perpendicular to the axis and drawn either above or below it; and we have

$$+a\sqrt{-1}=a_{+\frac{\pi}{2}}, \text{ and } -a\sqrt{-1}=a_{-\frac{\pi}{2}}.$$

Reciprocally, every perpendicular to this axis is represented, in conformity with the above

* See January, February and March Magazine.

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notation, by $a_{\pm\frac{\pi}{2}}$ and is, therefore, by definition, a mean proportional between a_0 and $a_{\pm\pi}$, or between $+a$ and $-a$. It is therefore an imaginary of the form $\pm a\sqrt{-1}$.

Cor. 1.—As signs of position, $\pm\sqrt{-1}$ is identical with $1_{\pm\frac{\pi}{2}}$.

Cor. 2.—Moreover, since $-1=1_{\pm\pi}=e^{\pm\pi\sqrt{-1}}$, we have also $\pm\sqrt{-1}=1_{\pm\frac{\pi}{2}}=e^{\pm\frac{\pi}{2}\sqrt{-1}}$.

Cor. 3.—So-called imaginary quantities are quite as real as positive or negative quantities, and differ from them only in position, being in fact perpendicular to them.

M. Francais argued that this theory of signs was more consistent than the ordinary one of Cartesian geometry, where, as abscissas and ordinates, two kinds of positive and two kinds of negative quantities were admitted. He contended that having once defined positive and negative quantities, as laid off parallel to the axis of abscissas, it was illogical to admit others not comprised in the definition, and that the common theory was thus faulty in admitting two incompatible principles where one was sufficient.

THEOREM II.—The sign of position $1_\alpha=e^{\alpha\sqrt{-1}}$.

Demonstration.—Let the semi-circumference of a unit circle be divided in the direction of positive arcs into m equal parts, and radii be drawn to the points of division; these radii will form a progression both as to magnitude and position, by definition. The two extremes being $1_0=+1$, and $1_\pi=-1=e^{\pi\sqrt{-1}}$, the means $1_{\frac{\pi}{m}}, 1_{\frac{2\pi}{m}}, \ldots\ldots 1_{\frac{(m-1)\pi}{m}}$, will be

$$e^{\frac{\pi}{m}\sqrt{-1}},\ e^{\frac{2\pi}{m}\sqrt{-1}},\ \ldots\ldots\ e^{\frac{(m-1)\pi}{m}\sqrt{-1}};$$

or, in general, $1_{\frac{n\pi}{m}}=e^{\frac{n\pi}{m}\sqrt{-1}}$; and as $\frac{n\pi}{m}$ may be any angle whatever, we have finally $1_\alpha=e^{\alpha\sqrt{-1}}$.

From this theorem M. Francais drew the following corollaries:

1. That by taking the logarithms of each member of the last equation, $\alpha\sqrt{-1}=\log(1_\alpha)$; showing that, in the geometry of position, arcs of circles are the logarithms of the corresponding radii, being affected with the sign $\sqrt{-1}$ since they are perpendicular to the axis of reference; explaining also the expression, "imaginary arcs of a circle are logarithms," and giving a rational interpretation of the symbolic equation

$$\frac{\pi}{2}\sqrt{-1}=\log(\sqrt{-1}).$$

2. That since $a_\alpha=a.1_\alpha$, we have also $a_\alpha=a.e^{\alpha\sqrt{-1}}$.

3. That since $e^{\alpha\sqrt{-1}}=\cos\alpha+\sin\alpha\sqrt{-1}$, it follows that $a_\alpha=a\cos\alpha+a\sin\alpha.\sqrt{-1}$, or that to express a directed right line, we must take the sum of its projections in two rectangular co-ordinate axes; each projection being taken with its proper sign of position.

4. That for any such lines we may substitute any number, provided that the sum of the projections of the latter is equal to the sum of the lines themselves: that is, we may write $a_\alpha, b_\beta, \ldots. m_\mu$ for x_ξ, provided we have

$$\text{(A)}\quad x.e^{\xi\sqrt{-1}}=a.e^{\alpha\sqrt{-1}}+b.e^{\beta\sqrt{-1}}+\ldots.+m.e^{\mu\sqrt{-1}},$$

$$\text{or (B)}\quad\begin{cases} x\cos\xi=a\cos\alpha+b\cos\beta+\ldots.+m\cos\mu, \\ x\sin\xi=a\sin\alpha+b\sin\beta+\ldots.+m\sin\mu, \end{cases}$$

and conversely.

If the lines a_α, b_β, x_ξ, etc. form a closed polygon, (B) will be satisfied, and hence for any given line may be substituted a series of others, forming with it a closed polygon; conversely for a series of lines forming an unclosed polygon may be substituted the closing line.

The application of these remarks to the theory of the composition and resolution of forces is evident. On this point M. Francais briefly says, "This theory which has always involved some difficulties is thus reduced to a problem of the Geometry of Position."

THEOREM III.—The sign of position 1_α may also be written $1^{\frac{\alpha}{2\pi}}$, that is to say $1_\alpha=1^{\frac{\alpha}{2\pi}}$.

Demonstration.—If the unit circle be divided into m equal parts and the radii be drawn, they will form a progression whose extremes are unity. Hence $1_{\frac{2\pi}{m}}=1^{\frac{1}{m}}$, $1_{\frac{4\pi}{m}}=1^{\frac{2}{m}}$, ... $1_{\frac{2n\pi}{m}}=1^{\frac{n}{m}}$. Let then $\frac{2n\pi}{m}=\alpha$; we shall have $\frac{n}{m}=\frac{\alpha}{2\pi}$, and consequently $1_\alpha=1^{\frac{\alpha}{2\pi}}$.

Cor. 1.—It follows from this theorem: 1°, that the above radii denote the m mth roots of unity; 2°, these roots are all equal, differing only in their positions; 3°, they are all equally

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real, being represented by lines given both in magnitude and position.

Cor. 2.—Comparing the last two theorems we obtain at once the well-known values of these roots, which may be expressed, in general, by

$$1^{\frac{n}{m}} = e^{\frac{2n\pi\sqrt{-1}}{m}} = \cos\frac{2n\pi}{m} + \sin\frac{2n\pi}{m} \cdot \sqrt{-1}.$$

He then proposes the substitution, for $+$, $-$ and $\pm\sqrt{-1}$, of 1_0, $1_{\pm\pi}$, $1_{\frac{\pi}{2}}$, in connection with the general sign $1_{\pm a}$; an additional advantage over that already suggested being that $+$ and $-$ will indicate addition and subtraction only, and so have but one meaning.

THEOREM IV.—All the roots of an equation of any degree are *real* and may be represented by lines given in magnitude and position.

Demonstration.—It has been shown that every equation of any degree whatever is always decomposable into real factors of the first or second degree, and hence it is sufficient to show that the root of an equation of the second degree can be represented by lines given in magnitude and position. Now the roots of an equation of the second degree, being of the form $x = p \pm \sqrt{q}$, can at once be constructed by the foregoing rules; for, 1°, if q is positive, x will be the sum or difference of two positive or negative quantities, laid off on the axis; 2°, if q is negative, x will be a right line drawn from the origin, the co-ordinates of whose extremity are p and $\sqrt{q}$.

M. Francais concluded his communication as follows:

Such is a very brief sketch of the new principles on which it seems to me desirable and necessary to found the geometry of position, and which I submit to the judgment of geometers. Being in direct conflict with the commonly received ideas concerning so-called imaginary quantities, I expect they will encounter many objections; but I dare to think that their thorough examination will show them to be well founded, and that the consequences I have drawn from them, strange as at first sight they may seem, will nevertheless be found in harmony with the most rigorous logic. I ought, moreover, to acknowledge that the germ of these ideas is not my own. I found it in a letter to my late brother from M. Legendre, in which this great geometer gave (as something he himself had derived from another, and purely as a matter of curiosity) the substance of my definitions of proportion and ratio—theorem I. and cor. 3 of theorem II.; but the latter was a mere suggestion, and only justified by a few applications. To myself, therefore, belongs only the credit due to the manner in which these principles have been set forth, and their proof, the notation, and the proposal of the symbol $1 \pm a$. I hope that the publicity thus given to my own results may induce the real author of these conceptions to make himself known and to publish his own researches on this subject.

In the same volume (IV. p. 71–73) of the annales which contained this paper from M. Francais, a note was inserted by the editor, Gergonne, to the effect that two years before (1811) in a letter he had written to M. de Maiziére on a communication which the latter had contributed to the first volume, he had suggested that "numerical quantities were perhaps improperly classified in a single series, and that, from their very nature, it seemed as if they should be arranged in a table of double argument, as follows:

$$\begin{array}{c}
\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
\cdots, -2+2\sqrt{-1}, \quad -1+2\sqrt{-1}, \\
+2\sqrt{-1}, +1+2\sqrt{-1}, +2+2\sqrt{-1}, \ldots \\
\cdots, -2+\sqrt{-1}, -1+\sqrt{-1}, +\sqrt{-1}, \\
+1+\sqrt{-1}, +2+\sqrt{-1}, \ldots \\
\cdots, -2, \quad -1, \quad \pm 0, \quad +1, \quad +2, \quad , \ldots \\
\cdots, -2-\sqrt{-1}, -1-\sqrt{-1}, -\sqrt{-1}, \\
+1-\sqrt{-1}, +2-\sqrt{-1}, \ldots \\
\cdots, -2-2\sqrt{-1}, -1-2\sqrt{-1}, -2\sqrt{-1}, \\
+1-2\sqrt{-1}, +2-2\sqrt{-1}, \ldots \\
\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\text{"}
\end{array}$$

So that, like Francais, he proposed that quantities of the form $n\sqrt{-1}$ should be laid off in a direction perpendicular to that in which the quantity n was measured, and that quantities having other directions should be represented by the sum of their projections on these two. He cites also from a letter of M. de Maiziere the following: "What I have advanced on imaginary quantities is quite novel, ... and I am sure you have already recognized its exactness," and again: "This will cease to be a paradox when I have proved that imaginaries of the second degree, and therefore of all degrees, are no more imaginary than negative quantities or imaginaries of the first degree, and that as regards the former we are exactly in the same position as were the Algebraists of the seventeenth century with respect to the latter." M. Gergonne disclaims any intention of depriving either Argand or Francais of the credit due them, but simply called attention to the fact that, after all, these conceptions were not so

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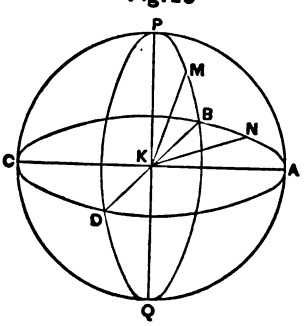
strange as would seem, since several had entertained them, and in closing he remarks that M. Francais' paper may be summarized in the following proposition:

"When, we seek a determinate but unknown length which is supposed to lie in a certain direction along a given line from a given point, while it really lies in the opposite direction, we obtain a negative expression; and if this length is not on the line at all, the expression will appear under an imaginary form."

M. Francais' paper called forth a second article from M. Argand, which appeared in Vol. IV., p. 133–147 of the Annales, wherein he called attention to his previous publication, and claims to have been the person to whom Legendre referred in his letter, he having submitted his first treatise to Legendre's examination. This second paper is, in the main, a restatement of the views advanced in the first; but in it he abandoned the use of the signs ~ and +, and returned to that of $\pm\sqrt{-1}$. He also added some further remarks, which are interesting as showing how he attempted to extend his theory to tri-dimensional space, and of which the following is a translation:

Let (Fig. 23) $\overline{KA}=+1$, $\overline{KC}=-1$, $\overline{KB}=+\sqrt{-1}$, $\overline{KD}=-\sqrt{-1}$; any other radius $\overline{KN}$, in the same plane, will be of the form $p+q\sqrt{-1}$; and, conversely, every expression of this form will denote a directed line of this plane.

Fig. 23



Draw now from the center K a perpendicular KP=KA to the plane. How shall this directed line be designated? Is it wholly independent of $\overline{KA}$ and $\overline{KB}$, or can it be referred analytically to the prime unit $\overline{KA}$, as are $\overline{KB}$, $\overline{KC}$? Guided by analogy it would seem that, taking the entire circumference as the unit angle, a directed radius making an angle a with $\overline{KA}$ would be expressed, from the principles already laid down, by 1^a; but this expression would be troublesome when a is a fraction, because it would then have more than one value. This objection would be met by the adoption of M. Francais' notation, 1_a; we should thus have $\overline{KA}=1_0$, $\overline{KB}=1_{\frac{1}{4}}$, $\overline{KC}=1_{\frac{1}{2}}$, $\overline{KD}=1_{\frac{3}{4}}$. We have considered angles reckoned from A above and below as positive and negative. Now, if we apply to the angles the rule we have adopted for lines, we should be led to regard imaginary angles as laid off in a direction perpendicular to that which corresponds to real angles. Suppose the semi-circumference ABC to revolve about AC, the point B describing the circle BPDQ; since we already have

angle $\overline{AKB}=+\frac{1}{4}=\frac{1}{4}.(+1)$,

angle $\overline{AKD}=-\frac{1}{4}=\frac{1}{4}.(-1)$,

we may write angle $\overline{AKP}=\frac{1}{4}\sqrt{-1}=\frac{1}{4}.1_{\frac{1}{4}}$; whence we conclude that

$$\overline{KP}=1_{\frac{1}{4}}\,1_{\frac{1}{4}}=1_{\frac{1}{4}\sqrt{-1}}=1^{\frac{1}{4}\sqrt{-1}}=$$

$$(1^{\frac{1}{4}})^{\sqrt{-1}}=(\sqrt{-1})^{\sqrt{-1}}.$$

This would seem to be the analytical expression required.

If on the circle BPD we take the point M, so that $\overline{BKM}=\mu$, we shall have, in like manner, angle $\overline{AKM}=\frac{1}{4}(\cos\mu+\sqrt{-1}\sin\mu)$, and writing for brevity $\cos\mu+\sqrt{-1}\sin\mu=\rho$, $\overline{KM}=1_{\frac{1}{4}\rho}=1.^{\frac{1}{4}\rho}=(1^{\frac{1}{4}})^{\rho}=(\sqrt{-1})^{\cos\mu+\sqrt{-1}\sin\mu}$ will be the general expression for all radii perpendicular to the primitive radius $\overline{KA}$.

Let us now seek an expression for $\overline{BKP}$. On the circumference ABC, the angles estimated from B in either direction are positive and negative, and real, and the plane BKP is perpendicular to their direction; it would thus seem that the angle $\overline{BKP}$, like $\overline{AKP}$, $=\frac{1}{4}\sqrt{-1}$, and that this should in like manner be true for any angle NKP, N being on the circumference ABCD; but that this conclusion is erroneous is evident from the fact that when N and C coincide, we should have $\overline{CKP}=\frac{1}{4}\sqrt{-1}$, whereas this angle is evidently $-\overline{AKP}=-\frac{1}{4}\sqrt{-1}$. To avoid this difficulty, observe that having adopted a direction for +1, there are an infinity of lines perpendicular to it, among which one is arbitrarily chosen as that of $\sqrt{-1}$. The general expression for every unity taken in one of these directions is, as we have just seen,

$$1_{\frac{1}{4}\rho}=1^{\frac{1}{4}\rho}=(\sqrt{-1})^{\rho}=(\sqrt{-1})^{\cos\mu+\sqrt{-1}\sin\mu}.$$

Conceive at the point A, an infinite number of directions perpendicular to the circumference at that point; one of these will be that of $\overline{KP}$; namely that one we have taken to construct the positive imaginary angles $+a\sqrt{-1}$; that is, for this case we have taken $\rho=1=\overline{KA}$. So, at C, the direction parallel to $\overline{KP}$ gave negative imaginary angles $-a\sqrt{-1}$; that is, we have made $\rho=-1=\overline{KB}$. Hence, with respect to the direction from B parallel to $\overline{KP}$,

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analogy would lead us to make $\rho = \sqrt{-1} = \overline{KB}$. Thus the expression for $\overline{BKP}$ will be $\frac{1}{4}(\sqrt{-1})^{\sqrt{-1}}$.

We will not further enlarge on these suggestions, and observe only in closing that the expressions a, a_b, a_{b_c}, which designate lines considered in reference to one, two and three dimensions, are only the first terms of a series which can be indefinitely extended.

If the above ideas are admissable, the question so often raised, as to whether every function can be reduced to the form $p+q\sqrt{-1}$, would be answered in the negative; and $\overline{KP} = (\sqrt{-1})(\sqrt{-1})$ would offer the simplest example of a quantity irreducible to this form, and as heterogeneous with respect to $\sqrt{-1}$ as is the latter with respect to $+1$.

It is true there are demonstrations going to show that the form $(a+b\sqrt{-1})^{m+n\sqrt{-1}}$ can always be reduced to the form $p+q\sqrt{-1}$; but we may be permitted to remark that those which make use of series are not conclusive so long as it is not proved that p and q are finite. Indeed it often happens in analysis that a series, which, from its very nature can only be true for real quantities, assumes an infinite value, or rather form, when it is made to represent an imaginary quantity; and in like manner it is presumable that a series composed of terms of the form $p+q\sqrt{-1}$ or a_b can become infinite if it is to express a quantity of the order a_{b_c}. As for those demonstrations which employ logarithms, they also seem somewhat obscure, because we have as yet no definite conceptions of imaginary logarithms. It is also necessary to ascertain whether the same logarithm may not belong at the same time to several quantities of different orders; a, a_b, a_{b_c}. Moreover the several values resulting from the radicals of the proposed expression is another source of ambiguity, so that one may succeed in rigorously reducing $(a+b\sqrt{-1})^{m+n\sqrt{-1}}$ to the form $p+q\sqrt{-1}$ without its being necessarily true that this expression has no other values of the order a_{b_c} irreducible to this form.

Before this second paper of Argand's had come to the notice of Francais, the latter also had endeavored to extend the new theory of imaginaries to tri-dimensional space. In the fourth Vol. of Gergonne's Annales a letter appeared from Francais, from which the following is an extract:

According to my previous definition, positive and negative angles are taken in the same plane, which for brevity I shall designate as the plane xy. It would then seem natural to suppose that imaginary angles are situated in planes perpendicular to xy, and this supposition would be justified by analogy alone; but its legitimacy may be shown as follows: the angle $+\beta\sqrt{-1}$ is a mean proportional, both as to magnitude and position, between $+\beta$ and $-\beta$; it is therefore situated with respect to the angle $+\beta$ as is the angle $-\beta$ with respect to it, which can only be so long as the plane of the angle $\pm\beta\sqrt{-1}$ bisects the angle of the planes $+\beta$ and $-\beta$. Now these planes coincide; therefore the plane of $\pm\beta\sqrt{-1}$ is perpendicular to the plane xy. Conversely, since every plane perpendicular to xy bisects the angles between the planes of the positive and negative angles, every angle β, in such a plane, may be considered a mean proportional in magnitude and position between $+\beta$ and $-\beta$; hence its value, in respect to both magnitude and position, is $\pm\beta\sqrt{-1}$.

From the above, and my 2nd and 3d theorems, it follows that $1_{\beta\sqrt{-1}} = e^{(\beta\sqrt{-1})\sqrt{-1}} = e^{-\beta}$

$$= 1^{\frac{\beta\sqrt{-1}}{2\pi}} = \cos(\beta\sqrt{-1}) + \sqrt{-1}\sin(\beta\sqrt{-1}).$$

Lambert's *hyperbolic sine and cosine* are thus reduced to the theory of circular arcs, Naperian logarithms, and roots of unity.

It further follows that

$$1_a \cdot 1_{\beta\sqrt{-1}} = e^{a\sqrt{-1}} e^{(\beta\sqrt{-1})\sqrt{-1}} = e^{(a+\beta\sqrt{-1})\sqrt{-1}} = 1_{a+\beta\sqrt{-1}}$$

$$= e^{a\sqrt{-1}}[\cos(\beta\sqrt{-1}) + \sqrt{-1}\sin(\beta\sqrt{-1})]$$

$$= \cos a\cos(\beta\sqrt{-1}) + \sqrt{-1}\sin a\cos(\beta\sqrt{-1}) + \sqrt{-1}.e^{a\sqrt{-1}}\sin(\beta\sqrt{-1}).$$

Whence

$$a_{a+\beta\sqrt{-1}} = a\cos a\cos(\beta\sqrt{-1}) + \sqrt{-1}\, a\sin a\cos(\beta\sqrt{-1}) + \sqrt{-1}.ae^{a\sqrt{-1}}\sin(\beta\sqrt{-1}).$$

Hence the projections of a on the three coordinate axes, or rather its three components, will be

$$a\cos a\cos(\beta\sqrt{-1}),\ \sqrt{-1}.a\sin a\cos(\beta\sqrt{-1}),\ \sqrt{-1}.a_a\sin(\beta\sqrt{-1}).$$

These, Monsieur, are the results I have reached; but I confess I am not yet satisfied with them. I desire to suppress wholly the old imaginary notation, as I have done for geometry of two dimensions; that is, for the latter I have reduced oblique lines of the form $A+B\sqrt{-1}$ to that of a_a, where a denotes the absolute length of the line, and a the angle it makes with the axis of reference. In tri-dimensional geometry, I desire to express the position of any line by a_{a_A}, a denoting the absolute length a the above angle and A the angle made by the plane of a with xy; but as yet all my efforts in that direction have proved unsuccessful. I trust some one more skillful than myself may succeed in filling up this gap. At all events, I am confident that the true method of extending our theory of imaginaries to tri-dimensional geometry consists in the consideration of imaginary angles.

In a postscript to this letter, Francais acknowledges the receipt of Argand's memoir, and that to the latter belongs the credit of the discovery of the geometrical representation of imaginaries.

He then adds:

In starting from the same principle we have

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reached different results. I have said above that I have not succeeded in reducing the expression for the position of any right line in space to the form a_{a_A}. The reasons for my failure are these: I attempted to make, from analogy

$$a_A = a.e^{A\sqrt{-1}} = a(\cos A + \sqrt{-1}\sin A)$$ whence

$$1_{a_A} = \left(e^{a\sqrt{-1}}\right)^{e^{A\sqrt{-1}}} = (\cos a + \sqrt{-1}\sin a)^{\cos A + \sqrt{-1}\sin A},$$

which, when $a = \frac{1}{2}\pi$, $A = \frac{1}{2}\pi$, gives

$$1_{\frac{1}{2}\pi.1_{\frac{1}{2}\pi}} = (\sqrt{-1})^{\sqrt{-1}},$$

which agrees with the result of M. Argand. But, developing the general case, we have

$$1_{a_A} = \left(e^{a\sqrt{-1}}\right)^{e^{A\sqrt{-1}}} = e^{(a.e^{A\sqrt{-1}})^{\sqrt{-1}}} =$$
$$e^{(a\cos A + \sqrt{-1}\,a\sin A)^{\sqrt{-1}}} =$$
$$e^{\sqrt{-1}.a\cos A}.e^{(\sqrt{-1}a\sin A)^{\sqrt{-1}}}$$
$$= [\cos(a\cos A) + \sqrt{-1}\sin(a\cos A)] \times$$
$$[\cos(\sqrt{-1}.a\sin A) + \sqrt{-1}\sin(\sqrt{-1}.a\sin A)] =$$
$$\cos(a\cos A)\cos(\sqrt{-1}.a\sin A) + \sqrt{-1}$$
$$\sin(a\cos A)\cos(\sqrt{-1}.a\sin A) +$$
$$\sqrt{-1}.e^{\sqrt{-1}.a\cos A}.\sin(\sqrt{-1}.a\sin A),$$

an expression which, on account of its doubly transcendental character, would seem inadmissable. On comparing it with

$$1_{\lambda+\mu\sqrt{-1}} = \cos\lambda\cos(\mu\sqrt{-1}) + \sqrt{-1}\sin\lambda\cos$$
$$(\mu\sqrt{-1}) + \sqrt{-1}.e^{\lambda\sqrt{-1}}\sin(\mu\sqrt{-1})$$

I rejected it altogether, because the angles a and A are easily found in terms of μ and λ by spherical trigonometry. In fact we have

$$\cos\lambda\cos(\mu\sqrt{-1}) = \cos a,$$
$$\sin\lambda\cos(\mu\sqrt{-1}) = \sin a\cos(A\sqrt{-1}),$$
$$\sin(\mu\sqrt{-1}) = \sin a\sin(A\sqrt{-1});$$

whence

$$\cos\lambda = \frac{\cos a}{\sqrt{1-\sin^2 a\sin^2(A\sqrt{-1})}},$$

$$\sin\lambda = \frac{\sin a\cos(A\sqrt{-1})}{\sqrt{1-\sin^2 a\sin^2(A\sqrt{-1})}}.$$

And therefore

$$1_{a_A} = [\cos a + \sqrt{-1}\sin a\cos(A\sqrt{-1})] \times \left\{1 + \frac{\sin a\sin(A\sqrt{-1})}{\sqrt{1-\sin^2 a\sin^2(A\sqrt{-1})}}\sqrt{-1}\right\}.$$

From this it seems to me clear that a_A cannot be determined as a_a was, and that the supposed analogy between angles and lines does not exist.

You must have remarked, Monsieur, that M. Argand does not prove my proposition $a_a = a(\cos a + \sqrt{-1}\sin a)$, and that this fundamental equality is, with him, simply a supposition justified only by a few examples.

On this remark M. Gergonne very justly observes that no demonstration was needed, inasmuch as Argand had *defined* the sum of directed lines as a certain composition of motions, "a very natural extension of the ordinary definition of Algebra."

M. Francais concludes:

I do not quite see why M. Argand (No. 12), in writing $2\pi = 1$, should introduce a new unit, rendering, it seems to me, the rest of his paper obscure. Finally, I should be loth to admit the correctness of his assertion that

$$(c\sqrt{-1})^{d\sqrt{-1}}$$

is irreducible to the form $A + B\sqrt{-1}$. In fact, we have

$$c\sqrt{-1} = e^{\log(c\sqrt{-1})} = e^{\log c + \log\sqrt{-1}}$$
$$= e^{\log c + \frac{1}{2}\pi\sqrt{-1}} = e^{\log c}\,e^{\frac{1}{2}\pi\sqrt{-1}};$$

therefore,

$$(c\sqrt{-1})^{d\sqrt{-1}} = e^{(d\log c)\sqrt{-1}}e^{-\frac{1}{2}d\pi} = e^{-\frac{1}{2}d\pi}$$
$$[\cos(d\log c) + \sqrt{-1}\sin(d\log c)],$$

which is certainly of the form $A + B\sqrt{-1}$. I, therefore, think myself correct in regarding the expression $(c\sqrt{-1})^{d\sqrt{-1}}$, which he assigns to the third dimension, as simply a conjecture open to serious objection.

On Nov. 13th, 1813, M. Servois addressed a letter to Gergonne, which is especially interesting as bearing upon the extension of Argand's theory to space of three dimensions. He objected first to Francais' proof of his first theorem. This proposition, that $\pm a\sqrt{-1}$ is a mean proportional in magnitude and position between $+a$ and $-a$, he claimed to consist of two, one of which, viz: that $\pm a\sqrt{-1}$, was a mean proportional as to position is not evident, and is indeed precisely what is to be proved. To this criticism Gergonne replied that, although Servois thinks it evident that $\pm a\sqrt{-1}$ is a mean as regards *magnitude*, between $+a$ and $-a$, it seemed to him difficult to see how such an expression, which, with its signs, is a *negation* of *magnitude*, could be a mean between two *reals*; that as regards magnitude, the mean could only be a; but, taking position into account, the mean must also be conceived under this new aspect, and is for this very reason a mean in position as well as magnitude, so that the interpretation of $\pm a\sqrt{-1}$ is reduced to the selection of a line which is situated with reference to $+a$ as $-a$ is to it.

Servois objected, secondly, that the new theory was not only founded merely on analogy, but was not even justified *a posteriori* by its applications. Emphasizing Argand's remark that it consisted in the use of a special notation, he char-

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acterized it as "a sort of geometric mask, superadded to analytic forms whose direct use was more simple and expeditious." For example, he says:

. . . take Argand's first application, where he proposes to develope $\sin(a+b)$ and $\cos(a+b)$. From the general formula $e^{a\sqrt{-1}} = \cos a + \sqrt{-1}\sin a$, I obtain $e^{(a+b)\sqrt{-1}} = \cos(a+b) + \sqrt{-1}\sin(a+b)$, and thence $e^{(a+b)\sqrt{-1}} = e^{a\sqrt{-1}}\, e^{b\sqrt{-1}} = (\cos a + \sqrt{-1}\sin a)(\cos b + \sqrt{-1}\sin b)$, or $e^{(a+b)\sqrt{-1}} = (\cos a\cos b - \sin a\sin b) + \sqrt{-1}(\sin a\cos b + \cos a\sin b)$; equating these two values of $e^{(a+b)\sqrt{-1}}$, and subsequently the real and imaginary parts separately, we have $\cos(a+b) = \cos a\cos b - \sin a\sin b$, $\sin(a+b) = \sin a\cos b + \cos a\sin b$. All the other geometrical applications are easily made in the same manner. They may be found in various works, and especially in "A Purely Algebraic Theory of Imaginary Quantities," by M. Suremain-de-Missery (Paris, 1801). The single application to algebra (close of Argand's treatise) seems to me quite unsatisfactory. I do not think it sufficient to find values for x which render the polynomial of less and less value; it is necessary, besides this, that the law of decrease should necessarily render it *zero*; and that it should be such that zero is not, so to speak, the asymptote of the polynomial.

After citing Euler's proof that

$$(\sqrt{-1})^{\sqrt{-1}} = e^{-\frac{1}{2}\pi},$$

in reply to Argand's assertion that this expression was irreducible to the form $p+q\sqrt{-1}$, he raises two other objections, which are important and given in full.

Accustomed to designate the position of a point in a plane by an angle and radius vector, geometers have certainly not been ignorant of the consequences of M. Francais' definition. . . . . But, content with distinguishing between the magnitude and position of a right line in a plane, they had not yet formed, from these two simple ideas, a single complex one, or rather they had not yet created a new *etre geometrique*, uniting at once both the ideas of magnitude and position. The length of a right line and its position, *i. e.* the angle it makes with a fixed axis, are two quantities, which we may term homogeneous; now, how can they be so combined as to form this new entity called a directed line? It seems to me this problem is not yet satisfactorily solved. If a is the length of the line and α the arc of the unit circle which measures the angle it makes with a fixed axis, undoubtedly we may in general represent the line by $\phi(a,\alpha)$, and the function ϕ must be determined by the essential condition it is to satisfy. Thus 1°, evidently $\phi(a,\alpha) = +a$ must correspond to $\alpha = 0$, $\alpha = 2\pi, \ldots, \alpha = 2n\pi$, and $\phi(a,\alpha) = -a$ to $\alpha = \pi$, $\alpha = 3\pi, \ldots, \alpha = (2n+1)\pi$; 2°, also, evidently from $\phi(a,\alpha) = \phi(b,\beta)$ we must have $a = b$, $\alpha = \beta$. But 3°, does it follow from the proportion $\frac{\phi(a,\alpha)}{\phi(b,\beta)} = \frac{\phi(c,\gamma)}{\phi(d,\delta)}$, as M. Francais says, that we must have $\frac{a}{b} = \frac{c}{d}$ and $\alpha - \beta = \gamma - \delta$? I do not see that this necessarily follows from the conception of ϕ. The very meaning of this ratio $\frac{\phi(a,\alpha)}{\phi(b,\beta)}$ is quite obscure. What indeed is meant by doubling, trebling, etc., a directed line? *A priori* this is not intelligible. M. Francais seems to have been aware of this difficulty, inasmuch as he speaks of the *sum* of directed lines only as a consequence of his first two theorems. Still, I do not object to admitting this condition as an essential characteristic of ϕ; but in that case the complete definition of a directed line will be a definition *nominis non rei*, or, in other words, *directed line* will be the name of a certain analytic function of the length and direction of a right line. From this it unfortunately follows that we are no longer constructing imaginaries, but simply reducing them to the same analytic form. However, let us see what this function is. It is, in the first place, clear that the expression $\phi(a,\alpha) = a.e^{\alpha\sqrt{-1}}$ satisfies the three foregoing conditions. In fact, we have 1° $\phi(a,o) = a.e^{o\sqrt{-1}} = a$, $\phi(a,\pi) = a.e^{\pi\sqrt{-1}} = a(\cos\pi + \sqrt{-1}\sin\pi) = -a$; 2° the equation $\phi(a,\alpha) = \phi(b,\beta)$ becomes $a.e^{\alpha\sqrt{-1}} = b.e^{\beta\sqrt{-1}}$, or, passing to logarithms, equating, and returning to numbers, $\alpha = b$, $\alpha = \beta$; 3° the above proportion, by similar transformations becomes $\frac{a}{b} = \frac{c}{d}$ and $\alpha - \beta = \gamma - \delta$. But is this form $a.e^{\alpha\sqrt{-1}}$ the only one which satisfies these three conditions? I think not, and it seems to me evident that they will be equally true if we substitute an arbitrary coefficient for the imaginary $\sqrt{-1}$. So that the form $a.e^{\alpha\sqrt{-1}}$ will, in my opinion, only be a special case of the analytic expression for a directed line, in its conventional signification. Are there any other conditions which follow from this signification? To this question no answer is made, nor do I either see any.

Again, 4° the table of double argument which you (Gergonne) propose, as applied to a plane supposed to be so divided into points or *infinitesimal* squares that each square corresponds to a number which would be its *index*, would very properly indicate the length and position of the radii vectores which revolve about the point or central square corresponding to ± 0; and it is quite remarkable that if we designate the length of a radius vector by a, and the angle it makes with the real line $\ldots, -1, \pm 0, +1, \ldots$ by α, the rectangular co-ordinates of its *extremity remote from the origin* by x, y, the real line being the axis of x, the point would be determined by $x + y\sqrt{-1}$, and consequently, since $x = a\cos\alpha$, $y = a\sin\alpha$, $a.e^{\alpha\sqrt{-1}}$. Thus we have a new *geometrical interpretation* of the function $a.e^{\alpha\sqrt{-1}}$ which, it seems to

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me, is of more value than that of MM. Argand and Francais; but certainly we should not thereby conclude that this was a new method of constructing, *geometrically*, imaginary quantities, for the above indices presuppose them. However this may be, it is clear that your ingenious tabular arrangement of numerical magnitudes may be regarded as a central slice (*tranche centrale*) of a table of triple argument representing points and lines in tri-dimensional space. You would doubtless give to each term a tri-nomial form; but what would be the co-efficient of the third term? For my part I cannot tell. Analogy would seem to indicate that the tri-nominal should be of the form $p\cos\alpha+q\cos\beta+r\cos\gamma$, α, β and γ being the angles made by a right line with three rectangular axes, and that we should have $(p\cos\alpha+q\cos\beta+r\cos\gamma)(p'\cos\alpha+q'\cos\beta+r'\cos\gamma)=\cos^2\alpha+\cos^2\beta+\cos^2\gamma=1$. The values of p,q,r,p',q',r' satisfying this condition would be *absurd*; but would they be imaginaries, reducible to the general form $A+B\sqrt{-1}$?

On this letter Hamilton remarks in his *Lectures on Quaternions*, (Preface, p. 57), "The six *non-reals* which thus Servois with remarkable sagacity *foresaw*, without being able to *determine* them, may now be identified with the then unknown symbols $+i$, $+j$, $+k$, $-i$, $-j$, $-k$ of the quaternion theory;" and it may here be interesting to quote (*North British Review*, 1866), from a letter of Hamilton on the discovery of these symbols:

Oct. 15, '58.

"P. S.—To-morrow will be the fifteenth birthday of the Quaternions. They started into life, or light, full grown, on the 16th of Oct., 1843, as I was walking with Lady Hamilton to Dublin, and came up to Brougham Bridge, which my boys have since called the Quaternion Bridge. That is to say, I then and there felt the galvanic circuit of thought to *close;* and the sparks which fell from it were the *fundamental equations between i, j, k; exactly such* as I have used them ever since. I pulled out, on the spot, a pocketbook, which still exists, and made an entry, on which, *at the very moment*, I felt that it might be worth my while to expend the labor of at least ten (or it might be fifteen) years to come. But then, it is fair to say that this was because I felt a *problem* to have been at that moment *solved*—an intellectual want *relieved*—which had *haunted* me for at least *fifteen years before*. *Less than an hour* elapsed before I had asked and obtained leave of the Council of the Royal Irish Academy, of which society I was at that time president, to *read*, at the *next general meeting*, a *paper* on Quaternions, which I accordingly *did* on Nov. 13th, 1843."

It is also proper here to add a disclaimer from Gergonne as to any thought of the extension of his table to tri-dimensional space, until after the appearance of Argand's and Francais' papers; and that even then he saw no way by which to effect that result.

The above letter from M. Servois called forth a reply from Francais (Annales, Vol. IV., p. 364–367), and a third paper from Argand (Annales, Vol. V., p 197–209). In the former, Francais sustains Gergonne, who had already said that Servois asked too much of the new theory, demanding rigorous demonstrations of that which, as in the early history of negative quantities or the calculus, was perceived by a sort of instinct, the proofs of whose fundamental principles the earlier writers were not in a state to produce. He then adds a few examples of the facility with which one might pass from the proposed to the ordinary notation.

The equation of a triangle whose base coincides with the axis of reference is $a_\alpha+b_{-\beta}=c$, whence

$$a\cos\alpha+b\cos\beta=c, \text{ and } a\sin\alpha-b\sin\beta=0,$$

or, taking the sum and difference of the squares

$$a^2+b^2+2ab\cos(\alpha+\beta)=c^2,$$
$$a^2\cos 2\alpha+b^2\cos 2\beta+2ab\cos(\alpha-\beta)=c^2.$$

The equation of the circle referred to the center is $a_\phi=x+y\sqrt{-1}$, whence

$$a\cos\phi=x,\ a\sin\phi=y,\ x^2+y^2=a^2.$$

The equation of a circle referred to a diameter is $\rho_\phi+\sigma_{\frac{1}{2}\pi-\phi}=2a$, whence

$$\rho\cos\phi+\sigma\sin\phi=2a,\ \rho\sin\phi-\sigma\cos\phi=0,$$
$$\rho^2=2a\rho\cos\phi,\ x^2+y^2=2ax.$$

The equation of an ellipse referred to the focus is $\rho_\phi+(2a-\rho)_\Psi=2e$, whence

$$\rho\cos\phi+(2a-\rho)\cos\Psi=2e,$$
$$\rho\sin\phi+(2a-\rho)\sin\Psi=0,\ \rho=\frac{a^2-e^2}{a-e\cos\phi}.$$

The reply of Argand is appended.

The new theory of imaginaries, already referred to several times in this publication, has two distinct and independent objects; it seeks, first, to render intelligible certain expressions whose presence in analysis has been inevitable, but which have not yet been referred to any known evaluable quantity; and, second, it presents a method, or a particular notation which employs geometric symbols concurrently with the ordinary algebraic signs. Hence,

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from this double point of view, two questions arise: Has it been rigorously shown that $\sqrt{-1}$ represents a line perpendicular to those denoted by $+1$ and -1? Can the notation of directed lines furnish, in certain cases, demonstrations and solutions preferable either for their simplicity or brevity, etc., to those which they are intended to replace?

The first of these will, perhaps, always be open to discussion so long as we seek to establish the meaning of $\sqrt{-1}$ by analogy, from the commonly received ideas on positive and negative quantities and their ratios. Negative quantities have been and are still the subject of discussion; it will, therefore, be all the easier to raise objections to the new theory of imaginaries. But this difficulty will vanish if, with M. Francais, we *define* what is meant by a ratio of magnitude and position between two lines. Indeed, the relation between two such lines may be conceived of with all necessary precision. Whether this relation be called *ratio* or something else, it may always be made the subject of exact reasoning, and its consequences, in analysis and geometry, of which M. Francais and myself have given some examples, may be traced. The only remaining question, then, is whether it is proper to designate this relation as a *ratio* or *proportion*, words which already possess, in analysis, a determinate and fixed meaning. Now, this is permissible, because the new meaning is an *extension*, not a *contradiction*, of the old one. The latter is so generalized that the ordinary meaning becomes, so to speak, a particular case of the new one. There is then, no question here of *demonstration*.

Thus, for the analyst who first wrote $a^{-n}=\frac{1}{a^n}$, this equation was a definition of negative exponents, not a proposition proved or to be proved. All that it was incumbent upon him to show was that this definition was only a generalization of that of positive exponents, the only ones before known, and so for fractional, irrational and imaginary exponents. It has been said that Euler proved $(\sqrt{-1})^{\sqrt{-1}}=e^{-\frac{1}{2}\pi}$. The word *proved* may be exact if we mean that this equation is derived from $e^{x\sqrt{-1}}=\cos x+\sqrt{-1}\sin x$, which is readily shown to be the case; but it is not so as regards this latter; for to show that a certain expression has a definite value, implies the previous definition of the expression. But is there any definition of imaginary exponents antedating the so called demonstration of Euler? It seems not. When Euler sought to evaluate $e^{x\sqrt{-1}}$, he naturally resorted to the theorem $e^z=1+\frac{z}{1}+\frac{z^2}{1.2}+\ldots$ previously demonstrated for all *real* values of z. By making $z=x\sqrt{-1}$ he found

$$e^{x\sqrt{-1}}=1+\frac{x\sqrt{-1}}{1}-\frac{x^2}{1.2}-\ldots;$$

whence he concluded, not that $e^{x\sqrt{-1}}=\cos x+\sqrt{-1}\sin x$, but that, if the expression $e^{x\sqrt{-1}}$ was defined as representing a quantity equal to $\cos x+\sqrt{-1}\sin x$, we should thereby bring both real and imaginary exponents under the same law. Here again, then, we have the extension of a principle, not the demonstration of a theorem.

It is also by an extension of principles that I was led to regard $(\sqrt{-1})^{(\sqrt{-1})}$ as representing a perpendicular to the plane ± 1, $\pm\sqrt{-1}$. The two results conflict, and I certainly have not insisted upon my own; I only wish to observe that MM. Francais and Servois have attacked it from considerations which are after all of the very nature of those on which I relied to establish it.

But if the above perpendicular cannot be expressed by $(\sqrt{-1})^{\sqrt{-1}}$, how then shall it be represented? Or, rather, can any expression be found, whose adoption, as the representative of the perpendicular, shall bring all directed lines whatever under a common law, as is already the case for every line of the plane ± 1, $\pm\sqrt{-1}$? This is a question which must be of interest to geometers, at least to those who admit the new theory. To return to the original question, I observe that whether $\sqrt{-1}$ does or does not represent the perpendicular on ± 1 must depend upon the meaning of the word *ratio*; for it is agreed by all that

$$+1:\sqrt{-1}::\sqrt{-1}:-1 \text{ or that } \frac{\sqrt{-1}}{+1}=\frac{-1}{\sqrt{-1}}.$$

So that M. Servois' objection to Francais' proof of his first theorem, viz: "That it is not proved that $\pm a\sqrt{-1}$ is a mean, as to position, between $+a$ and $-a$" is equivalent to the assertion that the word *ratio* has no reference to position. In its usual acceptation, this is true; and on the other hand, it may be said that, in the conception of a ratio between quantities with different signs, the signs must be regarded. In the new meaning, direction *and* magnitude make up the idea of ratio. It is thus seen to be a question of words, decided by the exact definition given by Francais, which is an extension of the usual one.

The second point under discussion is more important. Doubtless no truth is reached by the notation of directed lines which cannot be attained by ordinary methods; but which method is the simplest? This question is, I think, worthy of examination. It is to the influence of methods and notations on the progress of the science, that modern mathematics owes its superiority. So that when anything new of this kind appears, we may at least examine it in this respect. Since the publication of the new theory, M. Servois alone has expressed an opinion on this point, and his opinion is not favorable to the new notation. Analytic formulæ seem to him more simple and expeditious. I would, however, claim for my method a more careful examination. I admit that it is novel, and that the mental operations it requires, although quite simple, demand some familiarity in order that they may be performed with the ease which follows practice in the ordinary operations of

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Algebra. Some of the theorems I have proved seem to me easier than the corresponding purely analytic processes. This is, perhaps, an author's illusion, and I will not insist upon it; but I claim with more confidence the superiority of the method of directed lines for the demonstration of the Algebraic Theorem: "Every polynomial $x^n+ax^{n-1}+\ldots$ is decomposable into factors of the first or second degree." I feel it necessary to resume this demonstration, not only to reply to the objections of M. Servois, but also to show more fully how easily it is derived from the new principles. The importance and difficulty of this theorem, which has tasked the skill of the best geometers will, I think, excuse, in the eyes of the reader, some repetition. The demonstrations previously given may, I believe, be classified under two heads: Those of the first-class depend on certain metaphysical principles relating to the transformation of functions, which are doubtless true in themselves, but which, properly speaking, are not susceptible of rigorous proof. They are a sort of *axioms* whose truth cannot be appreciated unless we already grasp the *spirit* of Algebraic analysis; whereas to admit the truth of a *theorem*, it is sufficient to know the principles of this analysis; that is, to understand its definitions and language. Hence demonstrations of this kind have been frequently attacked. The *Recueil*, in which these remarks appear, offers several examples, and the appearance of such discussions is an indication of the fact that such reasoning is not above reproach.

In other cases the proposition to be established is approached directly, by showing that there is always at least one quantity of the form $a+b\sqrt{-1}$, which, when substituted for x, renders the polynomial zero; that is to say, that this polynomial may always be resolved into factors of the first or second degree. This is the method of Lagrange. This great geometer has shown that the previous methods of d'Alembert, Euler, Foncenex, etc., are inadequate (Résolution des equations numériques. Notes IX. and X). Some of them resorted to series, others to auxiliary equations; but they did not prove, as they should have done, that the co-efficients of these series and equations were always real. These geometers admit implicitly the principle that "if a problem involving an unknown quantity can be resolved in n ways, it must lead to an equation of the *nth* degree." Lagrange himself regards this legitimate, although he does not use it in the above-cited demonstrations. Now, may it not be said that this principle, probably true as it is, is not demonstrated, and belongs to that class of axioms above referred to? Especially would it seem as if this principle, which in theory is among the first to be demonstrated, was out of place, dependent as it is upon no little familiarity with the practice of the science. This remark is not a mere quibble, which, as regards conceptions deserving the respect of all geometers, would be as out of place as it is useless, but is made simply to show the difficulty in the way of a satistory treatment of this subject.

It would appear from the above that a demonstration at once simple, direct and rigorous is worthy the attention of geometers. I shall, therefore, resume that of my previous paper; but, to avoid all ambiguity, shall free it from any consideration of vanishing quantities. It will be convenient to restate briefly the first principles of the theory of directed lines.

Having taken $\overline{KA}$ as the direction of positive quantities, the opposite direction $\overline{AK}$, will be, as usual, that of negative quantities. Drawing the perpendicular $\overline{BKD}$ through K, one of the directions $\overline{KB}$, $\overline{KD}$, the former say, will correspond to imaginaries of the form $+a\sqrt{-1}$, the latter to those of the form $-a\sqrt{-1}$. The line drawn above the letters indicates that direction is considered, and, when we are only concerned with length, is suppressed. Assuming arbitrarily the points F, G, H, ... , P, Q, we have $\overline{FG}+\overline{GH}+\ldots+\overline{PQ}=\overline{FQ}$. This is the law of addition. If, between four lines, there exists the relation $\frac{\overline{AB}}{\overline{CD}}=\frac{\overline{EF}}{\overline{GH}}$, and, in addition, the angle between $\overline{AB}$, $\overline{CD}$ is equal to that between $\overline{EF}$, $\overline{GH}$, these lines are said to be *in proportion*. Hence the law of multiplication; for a product is merely a fourth term in a proportion whose first term is unity.

It is to be observed that these two rules are independent of any opinion one may have on the new theory. If it is desirable that $\sqrt{-1}$, a symbol to which the practice of Algebra continually gives rise, and which, sometimes called absurd, has yet never given absurd results, if it is desirable I repeat that this symbol should remain meaningless, while still not being zero, this will give rise to no difficulty. Directed lines will only be the *symbols* of numbers of the form $a+b\sqrt{-1}$. The above rules will be none the less true, but instead of deducing them *a priori* from purely metaphysical considerations, the first will depend on a simple construction. The second will be an immediate consequence of the formulæ $\sin(a+b)=\sin a\cos b+\ldots$: and therefore the use of these rules may give demonstrations entirely satisfactory.

Directed lines will then be symbols of the numbers $a+b\sqrt{-1}$. Like them they are susceptible of increase, decrease, multiplication, division, etc.; they will, as it were, correspond throughout, function for function, and, in a word, *represent* them completely. Hence, from this point of view, concrete quantities will represent abstract numbers; but conversely abstract numbers cannot represent concrete quantities. In what follows, the accents and subscripts are used to indicate the absolute magnitude of the quantities to which they are affixed; thus, if $a=m+n\sqrt{-1}$, m and n being real, it is understood that a_1 or $a'=\sqrt{m^2+n^2}$. Let then

$$y_x=x^n+ax^{n-1}+bx^{n-2}+\ldots+fx+g$$

be the proposed polynomial, n being a whole number; $a, b, \ldots . f, g$ may be of the form $m+n\sqrt{-1}$. We are to prove that we

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may always find a quantity such that, substituted for x, $y_x=o$. The polynomial may be constructed for any value of x by the preceding rules. Taking K as the initial point, P as the final one, $\overline{KP}$ will express this polynomial, and it is to be shown that x may be so determined as to cause P to coincide with K. Now, if among all the possible values of x, there is no one of which this is true, the line $\overline{KP}$ cannot become null; and of all the values of $\overline{KP}$ there will necessarily be one smaller than the rest. Designate this minimum value of x by z; then $y'_{(z+i)}<y'_z$ cannot be true, whatever the value of i. Now, developing, we have

$$(A)\quad \begin{cases} y_{(z+i)}=y_z+ \\ \qquad [nz^{n-1}+(n-1)az^{n-2}+\ldots.+f]i+ \\ \left\{\frac{n}{1}\cdot\frac{n-1}{2}z^{n-2}+\ldots.\right\}i^2+\ldots. \\ \qquad +(nz+a)i^{n-1}+i^n. \end{cases}$$

As the co-efficients of the several powers of i may become zero, and this is a special case, it is better to replace the above equation by

$$(B)\quad y_{(z+i)}=y_z+Ri^r+Si^s+\ldots.+Vi^v+i^n;$$

and so make the solution general; R, S and V not being zero and the exponents $r, s, \ldots, v, n$ being increasing. Observe that if all the coefficients of (A) were zero, the equation would reduce to $y_{(z+i)}=y_z+i^n$. Making then $i=\sqrt[n]{-y_z}$, we shall have $y_{(z+i)}=o$, and the theorem would be established for this case, which in what follows may therefore be set aside. We shall then suppose that the second member of (B) has at least three terms. With this premise, construct $y_{(z+i)}$, taking $\overline{KP}=y_z$, $\overline{PA}=Ri^r$, $\overline{AB}=Si^s$, $\ldots.$, $\overline{FG}=Vi^v$, $\overline{GH}=i^n$; we shall have $y'_z=\overline{KP}$, $R'i_1^r=PA$, $S'i_1^s=AB$, $\ldots.$, $V'i_1^v=FG$, $i_1^n=GH$; for evidently, in general, $p'q'=(pq)'$.

$y_{(z+i)}$ will be represented by the broken or straight line

$$\overline{KPAB\ldots FGH}, \text{ or by } \overline{KH};$$

and it is to be proved that we have $KH<KP$.

Now the quantity i may vary in two ways:

1°. In *direction*; and it is clear that if it varies by an angle a, its power i^r will vary by an angle ra. Let then a be the angle by which $\overline{PA}=Ri^r$ is greater than $KP=y_z$. If i is made to vary by the angle $\frac{\pi-a}{r}$, $\overline{PA}$ will vary by the angle $\pi-a$; that is, the direction of $\overline{PA}$ will become opposite to that of $\overline{KP}$; so that the point A will be found on the line PK, prolonged, if necessary, through K.

2°. The direction of i being supposed fixed, we may, in the second place, cause it to vary in *magnitude*; and first, if $PA>KP$, we may diminish i till $PA<KP$, so that A will fall between K and P. Then, if the magnitude of i, so diminished, is not such that $R'i_1^r>S'i_1^s+\ldots.+V'i_1^v+i_1^n$, we may, by diminishing it still further, make this inequality true, for the exponents $s, \ldots., v, n$ are all greater than r. Now this inequality is equivalent to $PA>AB+\ldots.+FG+GH$; therefore the distance AH will be less than PA, and, consequently, if we describe a circle with A as a center and radius AP, the point H will lie within this circle, and it follows from elementary geometry, that K being on the prolongation of the radius PA, in the direction of the center A, we shall have $KH<KP$.

To follow this demonstration, I would ask the reader to make the diagram. By the application thereto of the above cited simple fundamental principles, it will be seen that, with the exception of the development (A) which is algebraic, the remainder of the demonstration is made, as it were, at sight, without any mental effort.

It is almost superfluous to dwell upon an objection which might be made to what precedes, namely, that if one undertook to diminish the value of x by the method prescribed for diminishing y'_x, one might never succeed, because the value of i, in the successive substitutions, might diminish by constantly decreasing quantities. Indeed, the contrary is not proved; but from this it only follows that the above considerations cannot furnish, at least without new developments, an approximative method, and this does not in the least invalidate the demonstration of the theorem. M. Servois' objection is easily answered. "It seems to me," he says, "that it is not enough to find values of x which render the polynomial constantly less; it is necessary, in addition, that the law of diminution should necessarily reduce the polynomial to zero, or, if I may use the expression, such that zero is not the *asymptote* of the polynomial." It has been proved that we may not only find for y'_x constantly diminishing values, but a value less than any assignable one. If the polynomial cannot be reduced to zero, its least value will then be other than zero, and in this case also the demonstration holds good. The close of M. Servois' sentence would seem to indicate that he makes a distinction between an infinitely small limit and one which is absolutely zero. If such was his meaning he might be answered in the words of M. Gergonne . . . . Doubtless M. Servois' difficulty arises from the equation of the hyperbola $y=\frac{1}{x}$. It is unquestionably true that in this equation, although we may assign to y a value less than any assignable one, y cannot become zero unless x is supposed infinite. But this is not the case in our demonstration; for certainly it is not an infinite value for x which will render the polynomial $y'x$ zero.

Let us now resume the question which has given rise to the above explanations. It may be asked if it is possible to translate what precedes into the ordinary language of analysis. It seems to me quite probable, although it may be difficult in this way to obtain so simple a result. To effect this it would seem necessary to assimilate the notation of imaginaries to that of directed lines, writing, for instance:

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$$\sqrt{a^2+b^2}\left\{\frac{a}{\sqrt{a^2+b^2}}+\frac{b}{\sqrt{a^2+b^2}}\sqrt{-1}\right\}$$

for $a+b\sqrt{-1}$;

$\sqrt{a^2+b^2}$ might be called the *modulus* of $a+b\sqrt{-1}$, and would represent the absolute length of the line $a+b\sqrt{-1}$, while the other factor, whose modulus is unity would denote its direction. We should only. prove 1° that *the modulus of the sum of several quantities is not greater than the sum of their moduli*, which is equivalent to saying that the line AF is not greater than the sum of the lines AB,BC,.... EF; 2° *that the modulus of the product of several quantities is equal to the product of their moduli.*

The further investigation of the relations between the notations I must leave to those more skillful than myself. If this attempt to obtain a purely analytic demonstration as simple as that derived from the new theory is successful, analysis will be the gainer in thus reaching, by an easy method, a result whose difficulties were not unworthy the notice of Lagrange himself. If, on the contrary, this attempt should prove unsuccessful, the notation of directed lines will retain an evident advantage over the ordinary one; and in either case the new theory will have rendered some small service to science.

In closing, I may be permitted to make a remark on a note from M. Lacroix (Annales, Vol. IV, p. 367). This learned professor says that the Philosophical Transactions of 1806 contain a memoir from M. Buée on the very subject of which M. Francais and myself have written. Now, it was in this same year that my essay appeared, a pamphlet in which I explained the principles of the new theory, and of which the paper inserted in Vol. IV of the *Annales* (p. 138) is but an extract; it is well known, too, that the publications of academies can appear only after the date which they bear. This is sufficient to prove that if the contribution of M. Buée was wholly his own, as is quite possible, it is also quite certain that I could have had no knowledge of his paper when my treatise appeared.

In the foot notes to the Preface of Hamilton's Lectures on Quaternions, the reader will find full references to the labors of other writers on this subjeet, including Warren (1828), Peacock, Ohm, Mourey (1828), Gauss, Buée (1806), Gompertz (1818), Carnot, Wallis (1685), MacCullagh, Argand, Francais, Servois, Grassmann, DeMorgan, Graves, De-Foncenex, Euler, etc. While giving full credit to the results of his predecessors and co-workers, Hamilton justly claims to be alone the founder of a *system*. Moreover, the fundamental conception of this system was radically different from those entertained by previous writers. In the latter inclined or perpendicular lines to the plus and minus axis were represented by imaginaries, whereas *all* unit lines in space are represented by Hamilton by distinct square roots of negative unity, they being all real. No *one* direction is assumed positive, nor is any system of reference chosen independent of the lines of the construction involved in any special problem.

In addition to the works of Hamilton, Tait and Kelland, may be especially mentioned the *Calcolo dei Quaternioni, Bellavitis, Modena*, 1858, and the original paper (Memoirs of the Italian Society, 1854), by the same author, which has also been translated from the Italian into French by Laisant (*Exposition de lá Méthode des Equipollences. Paris*, 1874); the *Théorie Elementaire des Quantités Complexes*, by Hoüel, Paris, 1874; the *Fonctions doublement périodiques*, of MM. Briot and Bouquet, and a treatise by Allégret, *Sur le Calcul des Quaternions de M. Hamilton*. Paris, 1862.

As possessing some historic interest may be added, in addition to the works cited in the above-mentioned Preface, Truel, 1786, referred to by Cauchy, Woodhouse (Phil. Trans. 1801), Khun, (Nouveaux Mémoires de Petersburg, Vol. 3), and *Le Calcul Directif*, a series of articles by Transom, in the *Nouvelles Annales de Mathématiques*, 1868.

A. S. HARDY.

ROUSSET'S DEEP SEA SOUNDER.—This device is chiefly novel in dispensing with the usual sounding line altogether, and therefore with the trouble of paying out and hauling in. It is the invention of a Russian engineer, M. Paul C. Rousset, of St. Petersburg, and consists of an ordinary registering log having an inflated balloon or float attached to its upper end, and a lead or sinker hung by a trigger from its bottom. The log is lowered into the sea and drops downward through the water in a vertical position, the sinker being underneath, and the balloon uppermost. In its descent the vanes revolve, and the indicator registers the depth. When it reaches the bottom the sinker is detached by the loose trigger, and the buoyancy of the balloon is such that it raises the log again to the surface, where it floats until it is picked up by the ship.

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ON THE CALCULATION OF DIMENSIONS AS DEPENDING ON THE ULTIMATE WORKING STRENGTH OF MATERIALS.

By Dr. J. WEYRAUGH, Professor at the Polytechnicum, Stuttgart. Translated by GEORGE RUDOLPH BODNER, Assoc. M. Inst. Civil Engineers.

From Selected Papers of the Institution of Civil Engineers.

I. LEADING POINTS OF VIEW.

In the choice of the admissible stresses for iron and steel either the ultimate strength or the limit of elasticity has been the starting point. The new method aimed at by German engineers depends on the ultimate strength only. There are no longer any representatives of the other school among German writers, although the stress produced by the working load is always kept below the ordinary limit of elasticity. Formerly the ultimate working strength* a (*Arbeitsfestigkeit*) was assumed as constant, so that a bar which had once sustained a certain static load, could also support it under a quicker application and with an indefinite number of repetitions. The question is, whether in the present state of knowledge a may not be expressed with smaller errors by a formula. If a formula is decided upon, the general algebraical expression for it,

$$a=f(xy\ldots), \quad \ldots \quad (1)$$

denoting that a is some function of x, y, . . . takes the place of the constant working strength

$$a=C,$$

where C is some constant used in the earlier method of determining dimensions. Various general formula for a have been proposed in Germany. Whichever of them be adopted the choice of a numerical expression may turn out to be different according to the material and experience of the individual, just as until now different values of $a=C$ have been in use. As, however, under the most favorable circumstances, no values universally correct can result from a formula, having regard to all unforeseen and uncontrollable influences (faulty material, unintentional distribution of stress, rust, shocks, &c.), so now, as formerly, factors of safety must be used, the choice of which depends upon the object of the structure and the judgment of the designer. In this way, even with the same numerical value of the working strength a different values are obtained for the admissible stress, just as when for the same assumed value of a, say 3,500 kilogrammes per square centimeter, different engineers chose 600, 700, and 800 as admissible stress. When the admissible stress per unit of area has been fixed, the necessary effective area of section is made, as hitherto,

$$F=\frac{\max B}{b}, \quad \ldots \quad (2)$$

max B being understood to mean the numerical value of the absolute maximum load.

The desired improvement (*Neuerung*) requires, as compared with the old method, only an altered choice of b.

II. WÖHLER'S LAW.

That under a frequent alternation of tension and compression a bar does not sustain the same stress as under a static load has probably long been everywhere appreciated. The same remark applies to variable stress, whether tensile alone or only compressive. Before Wöhler's time account had been already frequently taken of this in calculations.*

The formula given by German engineers aim mainly at substituting, instead of a mere guess (*Schatzung*) at the most suitable stress on every occasion, a certain consistency or regularity.

* Or resistance to fracture under the straining action produced by the working conditions of the material. See definition in IV.

* *Vide* under X., and Weyrauch, "Strength and Determination of the Dimensions of Structures of Iron and Steel." Translated by Prof. Jay du Bois, New York, 1877, Wiley, pp. 2 and 159.

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From the nature of the case no far-reaching accuracy can be attempted, but only a limitation of previous errors. Former rules depended more upon "feeling" than on definite experimental results. Still it was considered that they were to be preferred to the assumption of a constant working strength. Thus arose the recognition accorded to the experiments undertaken by Wöhler between the years 1859–70 on behalf of the Prussian Ministry of Commerce, in order to determine the capability of materials for resistance to repeated and alternating straining actions. A complete account of these experiments, is found is Wöhler's publications,* and Spangenberg, on continuing the experiments, confirmed his results.† In earlier experiments on the strength of materials, it was ascertained by a gradually increasing load what tensile, compressive or shearing stress, once for all, could break a bar whose sectional area was unity, and this quantity t was called the tensile, compressive, shearing or breaking strength of the material. By Wöhler's experiments it was shown, that, though a given stress t can break the piece by a single application, smaller stresses can produce fracture if they are often enough repeated.

Wöhler concluded from this that the change in the grouping of the molecules, which is produced by the varying stress, acts unfavorably on the resistance of the material. In that case fracture must take place more readily the greater the differences in the alternate stresses, because with these the change of position of the molecules also increases. With reference to these considerations, and on the bases of his experimental results, Wöhler enunciated the following law:

The fracture of a material may be effected not only by a static load producing stress equal to t, but also by often repeated vibrations producing stresses of which no one attains t. The differences of stress in so far affect the cohesion, that, as they increase, the minimum stress capable of causing fracture decreases. With the stress t the material is broken by a single application. Smaller stresses than t can produce fracture by many repetitions. The smaller the stress, the more numerous the repetitions necessary for fracture. Conversely, the stress may be greater, the fewer repetitions it is intended to make. According to these principles, in judging of the degree of safety of a structure, much depends on whether it is only expected to remain in use for a certain time, or whether it is intended for permanent durability.

III. REMARKS ON WÖHLER'S LAW.

That, since the experiments of Fairbairn,* Wöhler, and Spangenberg, apart from earlier experience, the ultimate working strength a can longer be considered constant, will scarcely be disputed. It is another question whether Wöhler's law forms a reliable basis for judgment. In Germany this has been pretty generally assumed, as the numerous methods of determining dimensions based upon it testify, of which Gerber's† has been adopted by the Bavarian Government.

The Launhardt-Weyrauch method, which has probably found the most general acceptance, also starts from Wöhler's law. If this law is recognized, it must still be admitted that further definition of it is desirable.

In Wöhler's experiments the load was applied at very brief intervals; nevertheless, the stresses required a certain time to attain their full magnitude; but there is no question of actual blows (*Stosse*). Now, what influences are respectively and separately due to the frequency of the application, the rate of increase, and the duration of the individual straining actions? The two latter influences have been neglected under the assumption of a constant ultimate working strength; in bridge design the first is ordinarily viewed too unfavorably, if considered in the light of Wöhler's results.

That the law in question is not absolutely essential to the explanation of a variable strength has been lately shown

* Wöhler in Zeitschrift für Bauwesen, 1860, 1863, 1866, 1870, *passim*.
† Spangenberg in Zeitschrift für Bauwesen, 1874, 1875, and Minutes of Proceedings Inst. C. E., vol. lx., p. 415.

* *Vide* Phil. Trans. 1864, p. 311, "Useful Information for Engineers," 3rd Series, 1866.
† Gerber in Zeitschrift des Bayerischen Arch. und Ing-Vereins, 1874.

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by Lippold.* He starts from the following law: "To break a bar a certain amount of mechanical work is necessary, and this can be accumulated in the material at once, just as well as by repeated loads. These loads must, however, be applied instantaneously, or so rapidly that vibrations arise." It is essential to this view, that only by means of vibrations can equal strain (*i. e.*, proportionate extension, or proportionate shortening, as the case may be), and with it equal stress and equal work, be attained by a load below that which produces t as by t itself, while less weight is attached to the repetitions of the straining action. Lippold arrives at formula for a, according to which the strength varies in the same manner as when based on Wöhler's law.

It is doubtless possible that in time, through speculation and experiment, safe foundations for a correct theory of properties relating to strength will be reached. The author, however, is not satisfied to rest contented till then with the certainly false assumption of constant strength. Smaller errors and greater safety for structures can already be attained through the results of Wöhler's experiments.

IV. ON THE STRENGTH OF MATERIALS.

To start from Wöhler's law, regarding it as purely empirical:

The words "often repeated" (II.) may be suppressed, and it may be left an open question what influences are concerned in the fracture of the piece. If, for the method hitherto used in determining dimensions, a new method is to be substituted, the latter must be sufficiently well founded, simple in its application, and in conformity with experience. At the same time it may be remembered that it is not a question of ingenious laws of unattainable accuracy, but of a useful guide for practical purposes. In the first place it has to be determined by a formula how the ultimate working strength a varies with the difference between successive stresses.

In developing or judging of this formula the results of experiment should find application, but if possible, only such as have been obtained with the same class of material and under exactly the same circumstances; for only in this way can the effects of varied loading be ascertained independently of foreign influences.

The variable resistance to fracture, a, is in Germany called, according to Launhardt, "ultimate working strength" (*Arbeitsfestigkeit*). The terms, too, of tensile strength, compressive strength, shearing strength, &c., are to be taken in a wider sense than hitherto, to mean the ultimate working strength a for tension, compression, shearing, &c. Three special values of the ultimate working strength are of particular interest.

I. The amount per unit of section of the resistance to fracture by a single application of a statical, or at any rate very gradually applied load, which hitherto has been alone considered, may be called "statical breaking strength," t, (*Tragfestigkeit*).

II. If, after every application of the load, the bar reverts to its original unloaded condition, and if all stresses are in the same sense,* *e. g.*, tension, compression, or shearing in one sense only, the greatest stress which can be sustained under the specified number of repetitions is called, according to Launhardt, the "primitive strength," u, (*Ursprungsfestigkeit*).

III. Finally, for strength as regards alternating stresses of equal intensity in opposite senses, *i. e.*, for tension and compression, or for shearing in opposite senses, these being due to vibrations taking place about the original position of unstrained equilibrium, the author has introduced the term "vibration-strength," s, (*Schwingungsfestigkeit*).

Of course the statical breaking strength t and the primitive strength u apply to either tension, compression, or shearing. If it be assumed, with Wöhler, that repetitions of the straining action are essentially dangerous to the material, u and s must be less the more

* *Vide* Organ für die Fortschritte des Eisenbahnwesens, 1879.

* "Direction" of a force, or a stress, is any line parallel to its line of action, and may be regarded indifferently as from left to right or right to left. "Sense" distinguishes between these two alternatives. Thus, if a force is exerted from right to left it is exerted in one sense; if from left to right, in the opposite sense. The two opposite senses may, if required, be distinguished as positive sense and negative sense. This use of "sense" is universal among French writers on mechanics, and helps precision of statement.

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repetitions are intended, and hence minima for a bridge which is to last for ever. In giving numerical values in the sequel the latter case is contemplated.

V. LAUNHARDT'S FORMULA.

Suppose a bar whose sectional area is unity to experience stresses in the same sense which vary between the maximum a and the minimum a'. The difference of stress is here

$$d=a-a',$$

and

$$a=d+a' \quad . \quad . \quad . \quad . \quad . \quad (3)$$

According to Wöhler's law a diminishes as d increases. From (3), and the definitions of the statical breaking strength t and primitive strength u, the two limits of value for a are

for $a'=0$, $a=d=u$,
" $d=0$, $a=a'=t$.

As according to Wöhler a should be a function of d,

$$a=fd \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where f is at present an unknown multiplier. It is known, however, that

for $d=0$ since $a=t$, $f=\infty$,
" $d=u$ " $a=d$, $f=1$.

For intermediate values of a the variation of f must be determined by considering experimental results obtained under circumstances, as nearly as possible, identical.

The coefficient chosen by Launhardt

$$f=\frac{t-u}{t-a} \quad . \quad . \quad . \quad (5)$$

corresponds to the best of these results, and fulfills the imposed conditions. Hence by (4)

$$a=\frac{t-u}{t-a}d=\frac{t-u}{t-a}(a-a');$$

and therefore, reducing,

$$a=u\left(1+\frac{t-u}{u}\cdot\frac{a'}{a}\right) \quad . \quad . \quad . \quad (6)$$

If B denotes the total load on a bar of any section, alternating between maximum and minimum values, the ratio of the less to the greater limit of stress is

$$\Phi=\frac{\min B}{\max R}=\frac{a'}{a}; \quad . \quad . \quad . \quad (7)$$

so that

$$a=u\left(1+\frac{t-u}{u}\cdot\frac{\min B}{\max B}\right) \quad . \quad . \quad (8)$$

The is Launhardt's formula.* It is applicable when a member of a structure is always subjected solely to tension, solely to compression, or solely to shearing stress in one sense, the values of t and u only, the statical breaking strength and the primitive strength for tension, compression, or shearing, as the case may be, having to be substituted.

VI. REMARKS ON LAUNHARDT'S FORMULA.

In order to ascertain whether Launhardt's choice of the coefficient f is applicable also to intermediate cases, equation (6) is to be solved for a, giving

$$a=\frac{u}{2}+\sqrt{\frac{u^2}{4}+(t-u)a'}, \quad . \quad . \quad . \quad (9)$$

where the + sign must be chosen before the radical, because a must be positive and not less than u; since, as defined in V., its least value is u, and greatest t.

The most complete results are those which Wöhler obtained† in making bending experiments with unhardened Krupp spring steel. This material showed for a statical breaking strength of about 1,100 centners per square inch (Rhenish), a primitive strength of $u=500$ centners per square inch; whence from equation (9) the ultimate working strength in this case must be

$$a=250+\sqrt{62{,}500+600\,a'}.$$

There follows for.....$a'=$	0	250	400	600	1,100
By Launhardt's equation.....$a=$	500	711	800	900	1,100
By Wöhler's experiments.....$a=$	500	700	800	900	1,100

For unhardened spring steel from Mayr of Werben the experiments also give $u=500$, $t=1{,}100$; while for hardened Krupp spring steel, the lowest values are $u=600$, and $t=1{,}200$.

* *Vide* Zeitsch. des Arch. und Ing-Vereins zu Hannover, 1873.

† Wöhler "Uber die Festigkeitsversuche mit Eisen und Stahl;" Berlin Zeitschrift für Bauwesen, 1870, pp. 7 and 14 of the reprint. As it is merely a question of comparison, the author retains Wöhler's original values and denominations.

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Wöhler obtained from bending experiments with iron for axles made by the Phœnix Company $t=550$, $u=300$; whence follows

$$a=150+\sqrt{12{,}500+300\,a'}.$$

For example, if $a'=240$, equation (9) gives for the ultimate working strength $a=440$; which agrees exactly with the value given by his tension experiments.

Unfortunately only a few among Wöhler's experiments give t, u, s, and intermediate values of a. Considering, however, that absolutely exact laws for constructive materials will certainly never result from experiments, that even in brands of iron acknowledged to be good, differences in the statical breaking strength t of as much as 40 per cent. occur, and that it is merely a question of finding a substitute for the still more rough and incorrect assumption of a constant a, even the preceding might suffice for practical purposes until more facts are accumulated.

Launhardt's formula (4) is the expression of Wöhler's law. By the latter the limits of value for f are also determined. In the first instance, the choice of the interpolation formula for f is arbitrary. Nevertheless, this choice appears to be well justified by the only experiments of Wöhler's suited for comparison. Neither results from other sources, nor experience, nor practical feeling are against it. Even for more exact determinations than those under consideration such an approximation ought to be considered satisfactory. To the author's mind, it would appear sufficient if the deviations of the real values of a from those given by the formula did not exceed the deviations from one another of real values of a in good and commonly used materials.

VII. WEYRAUCH'S FORMULA.

Suppose a bar of unit sectional area subjected to alternating straining actions in opposite senses. If then a be the numerical value of the greater, a' that of the lesser limit of stress, the difference of stress is $d=a+a'$, and therefore

$$a=d-a' \quad . \quad . \quad . \quad . \quad (10)$$

According to Wöhler, a diminishes as d increases, and is a function of d, so that as in V.,

$$a=fd \quad . \quad . \quad . \quad . \quad . \quad (10\text{A})$$

Since, by the definitions of the primitive strength u, and the vibration strength s in IV.,

for $a'=0$, $a=u=d$,
" $a'=s$, $a=s=\frac{1}{2}d$,

therefore the following conditions must be fulfilled:

for $a=u$, $f=1$,
" $a=s$, $f=\frac{1}{2}$.

Intermediate cases should depend on the results of experiment which, however, at present do not exist. In the meantime the two conditions just mentioned are fulfilled by the coefficient

$$f=\frac{u-s}{2u-s-a}; \quad . \quad . \quad . \quad (11)$$

hence, from (10A),

$$a=\frac{u-s}{2u-s-a}\,d=\frac{u-s}{2u-s-a}(a+a'),$$

and therefore

$$a=u\left(1-\frac{u-s}{u}\cdot\frac{a'}{a}\right) \quad . \quad . \quad . \quad (12)$$

If, now, for a bar of any section, max B is the numerical value of the absolutely greatest load, max B′ the numerical value of the greatest load in the opposite sense, distinguished from the other as negative, then the ratio of the less to the greater limit of stress is

$$\Phi=-\frac{\max B'}{\max B}=-\frac{a'}{a}; \quad . \quad . \quad . \quad (13)$$

whence from (12)

$$a=u\left(1-\frac{u-s}{u}\cdot\frac{\max B'}{\max B}\right) \quad . \quad . \quad (14)$$

This is Weyrauch's formula. It is always to be applied in those cases where a member of a structure is subject to stresses alternating between tension and compression, or between shearing actions in opposite senses. By u and a are to be understood, respectively, the primitive strength and ultimate working strength for the numerically greater of the two alternate stresses if they differ in amount.

VIII. REMARKS ON WEYRAUCH'S FORMULA.

If equation (12) be solved for a,

$$a=\frac{u}{2}+\sqrt{\frac{u^2}{4}-(u-s)a'} \quad . \quad . \quad (15)$$

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In this formulua, from (12),

$$(u-s)a'=au-a^2.$$

The maximum of this expression is found by differentiation with respect to a, thus:

$$\frac{d[(u-s)a']}{da}=u-2a=0,$$

to occur when $a=\frac{1}{2}u$, and the maximum value of

$$(u-s)a'=au-a^2=\frac{u^2}{4}.$$

Hence the expression under the radical in equation (15) can never become imaginary, and this refutes an objection in "Engineering" (vol. xxix., pp. 304, 341).

Wöhler found for alternations of tension and compression for "Phœnix" iron

$$u=2{,}190,\ s=1{,}170;$$

for Krupp cast steel for axles

$$u=3{,}510,\ s=2{,}050;$$

for shearing stress in opposite senses with the same material

$$u=2{,}780,\ s=1{,}610$$

centners per square inch (Rhenish). It is a decided defect that the choice of the coefficient f for the intermediate stages cannot for the present be checked by experiment. This is of course true of all empirical formulæ, which may be constructed on Wöhler's data for stresses in opposite senses. When, however, it is admitted that s and u are not equal, or, in other words, that the same ultimate working stress cannot apply in cases of alternation between tension and compression that applies to intermittent tension alone, it becomes evident that an interpolation formula must be adopted. The author considered that it ought to be built up by reasoning similar to Launhardt's, and hence in Germany the formulæ,

$$a=u\left(1+\frac{t-u}{u}\Phi\right) \text{ for positive } \Phi. \quad (16)$$

$$a=u\left(1+\frac{u-s}{u}\Phi\right) \text{ for negative } \Phi. \quad (17)$$

are always applied side by side. In both (16) and (17) t, u, and s are numerical values without sign [+or−], while the ratio Φ of the least to the greatest limit of stress is positive or negative according as the extreme alternate stresses are in the same or different senses. The results which are obtained by formula (17) do not at any rate contradict practical feeling or assumptions hitherto customary (*vide* X).

IX. ADMISSIBLE STRESS FOR IRON.

In determining the numerical values of the admissible stress per unit of area, Wöhler's experimental results must be applied. At the same time every illusion as to the universal applicability of the latter is to be put aside; just as formerly a new series of experiments on the statical breaking strength t was accepted without their results being henceforth exclusively used. If, for instance, in such cases a statical breaking strength of $t=3{,}870$ kilogrammes per square centimeter resulted, 3,500 perhaps, was taken as a low value; so, if not still more cautiously, similar judgment must be exercised in the choice of a. Beyond this, the help of factors of safety was always resorted to, and this must still be so in the future. In the following determinations particular reference is made to iron bridges. For simple compression, in accordance with the usual practice, the same limiting stresses as for tension are adopted.

Alternating stresses, either exclusively tensile, or exclusively compressive.—In what follows the numerical intensities of stress are expressed in kilogrammes per square centimeter. With iron for axles of the "Phoenix" Company, bending experiments of Wöhler's gave $t=4{,}020$, $u=2{,}190$; whence $\frac{t-u}{u}=\frac{5}{6}$; and by (16)

$$a=u\left(1+\frac{t-u}{u}\Phi\right)=2{,}190\left(1+\frac{5}{6}\Phi\right).$$

If the formula is to afford the desired security for any tensile or compressive stress, a start must always be made from the most unfavorable case of this stress. For the same iron, with the direct application of tensile stress, $u=2{,}190$ also; but $t=3{,}290$ only. Therefore take

$$\frac{t-u}{u}=\frac{3{,}290-2{,}190}{2{,}190}=\frac{1}{2},$$

very approximately; and suppose the ultimate working strength be further reduced by rounding off the value of u on the side of safety, to

$$a=2{,}100\left(1+\frac{1}{2}\Phi\right).$$

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If $\frac{1}{3}$ is chosen as a suitable factor of safety, the admissible stress per square centimeter then becomes

$$b=700\left(1+\frac{\Phi}{2}\right) \quad . \quad . \quad . \quad . \quad (18)$$

Alternation between tensile and compressive stresses.—For the Phoenix iron above-mentioned Wöhler found $u=2{,}190$, $s=1{,}170$; hence in this case $\frac{u-s}{u}=\frac{7}{15}$, and by (17),

$$a=u\left(1+\frac{u-s}{u}\Phi\right)=2{,}190\left(1+\frac{7}{15}\Phi\right).$$

Rounding off these values on the safe side by diminishing 2,190 to 2,100 and increasing $\frac{7}{15}$ to $\frac{1}{2}$, since Φ is negative, there results

$$a=2{,}100\ (1+\tfrac{1}{2}\Phi),$$

whence, with the factor of safety $\frac{1}{3}$ the admissible stress per square centimeter becomes

$$b=700\left(1+\frac{\Phi}{2}\right) \quad . \quad . \quad . \quad (19)$$

Shearing Stresses.—In most practical cases a and b for shearing stresses may be made $\frac{4}{5}$ of what they would be with the same ratio of stress Φ for tension and compression.* Therefore, generally,

$$b=560\left(1+\frac{\Phi}{2}\right) \quad . \quad . \quad . \quad (20)$$

where Φ is positive or negative, according as the alternating limits of stress are in the same or in opposite senses.

X. REMARKS ON THE CHOICE OF b.

It has been shown in the above that the stress per square centimeter may be generally expressed,

for positive Φ by $b=v\ (1+m\Phi)$. (21)
" negative Φ " $b=v\ (1+n\ \Phi)$. (22)

where v, m, n, are constants depending on the nature of the material and sense of stress, Φ the ratio of the less to the greater limiting stress. When the admissible stress per unit of area has been fixed, the necessary net sectional area is found by

$$F=\frac{\max B}{b}.$$

For iron, in particular, as explained in IX., there may be assumed for tension and compression $v=700$, $m=n=\frac{1}{2}$, so that very simply,

$$\left.\begin{aligned} b&=700\left(1+\frac{\Phi}{2}\right),\\ F&=\frac{\max B}{700\left(1+\frac{\Phi}{2}\right)}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (23)$$

By this threefold safety is attained if

$$t=3{,}150,\ u=2{,}100,\ s=1{,}050.$$

Smaller values of strength for bridges than these figures indicate are certainly not necessary, and have not been hitherto customary. Notwithstanding this, as has already been remarked in I., these values can have no universal application, and should they be thought too high for the material and the purpose, the following may, perhaps, be suitable: $v=640$, $m=n=\frac{1}{2}$; whence

$$\left.\begin{aligned} b&=640\left(1+\frac{\Phi}{2}\right),\\ F&=\frac{\max B}{640\left(1+\frac{\Phi}{2}\right)}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (24)$$

Different values also may be assigned to m and n; for steel, for instance, different values cannot be avoided.*

Exception† has been taken to the fraction $\frac{1}{2}$. With equal justice the choice of $b=700$ might have been considered dubious, and 687 preferred. It may suffice to answer that, in these objections, general and special facts have been confused.

When for booms of girders p is the dead load, q the total load per lineal meter, and $\Phi=\frac{\min B}{\max B}=\frac{p}{q}$ then

$$b=v\left(1+m\frac{p}{q}\right)=700\left(1+\frac{p}{2q}\right); \quad . \quad . \quad (25)$$

these latter numerical values for wrought iron being according to IX.

When the numerical values assumed for b, the admissible stresses for a static load, for alternations between tension and an unloaded condition, and for alternations between tension and compression of equal amount, would stand in

* *Vide* "Strength and Determination of the dimensions of Structures of Iron and Steel," by Dr. P. J. J. Weyrauch, pp. 81–88 *ante*.

* *Vide* Weyrauch "Strength and Determination," &c., pp. 60–68.
† *Vide* "Engineering," vol. xxix., p. 263.

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the ratio 3 : 2 : 1. The author is given to understand that this ratio has been adopted as a matter of experience in the practical construction of machinery, independently of Wöhler.

Launhardt quotes an older method of American engineers. According to this method, if tension alone alternating from 0 to 700 kilogrammes per square centimeter were admissible, for alternations of tension and compression the following formula was used:

$$F=\frac{\max B+\max B'}{700} \quad . \quad (26)$$

whence if $\Phi=\frac{\max B'}{\max B}$,

$$b=\frac{\max B}{F}=\frac{700}{1+\Phi} \quad . \quad (27)$$

Comparing this with (23):

For Φ . . =	0,	$\frac{1}{4}$,	$\frac{1}{2}$,	$\frac{3}{4}$,	1,
according to formula (27) b =	700,	560,	477,	400,	350
	(23) b =	700,	612,	525,	437,	350

Wöhler concluded from his own experiments that the following values were admissible for iron structures of unlimited duration:

For alternations between tension or compression only, and an unloaded condition, $b=1{,}100$ (above, 700), for alternations between equal tensile and compressive stresses, $b=580$ (above, 350).

Previous to his becoming acquainted with the Weyrauch formula, Launhardt recommended a provisional adoption of (26).

XI. ON THE LIABILITY TO BUCKLING.

In the preceding demonstration, the buckling strength has not been considered.

Other methods proposed in Germany and Austria have also left this question out of consideration,* as it was formerly almost universally the practice in those countries to calculate even the struts of lattice bridges for simple compression only. It was sought to avoid the risk of buckling by large moments of inertia of sections, and when necessary by fixing intermediate points. Since, however, the neglect of the liability to buckling had been noticed by American reviewers, the author first showed how it could be taken into account in the Italian edition of the work already frequently quoted. The following short demonstration may serve as a supplement to the English edition.

Of course it is not a question of improving the very defective theory of buckling of Euler and Navier, still less of reconstructing the empirical formulæ of Rankine and Gordon. Nevertheless, the author is so much convinced of the inaccuracy of the latter makeshifts, that it appears incredible to him how some English engineers, who remain contented with them, could raise objections on the score of inaccuracy to the formulæ given above.

According to the preceding (X), if F_d denote the requisite sectional area of a strut without liability to buckling, the stresses on which alternate between the maximum compression B_d and the minimum compression B_δ, then

$$F_d=\frac{B_d}{b}=\frac{B_d}{v\left(1+m\frac{B_\delta}{B_d}\right)}; \quad . \quad . \quad . \quad (28)$$

and for a bar, which is strained between the maximum compression B_d and the maximum tension B_t, there follows,

$$\text{for } B_d > B_t, F_d=\frac{B_d}{b}=\frac{B_d}{v\left(1-n\frac{B_t}{B_d}\right)} \quad . \quad (29)$$

$$\text{for } B_d < B_t, F_d=\frac{B_t}{b}=\frac{B_t}{v\left(1-n\frac{B_d}{B_t}\right)} \quad . \quad (30)$$

All stresses are to be substituted here as numerical values without signs.

XII. CONSIDERATION OF THE LIABILITY TO BUCKLING.

If for any strut or pillar, l be the length, F the sectional area, I the least moment of inertia of the section for axes through its center of gravity and lying in its plane, E the modulus of elasticity, t the statical breaking strength for simple compression only, δ a coefficient known from the theory of buckling depending on the method of securing the ends, let the following expression be introduced:

$$\mu=\frac{Ftl^2}{\delta EI}=\frac{Fl^2}{I\sigma} \text{ where } \sigma=\frac{\delta E}{t} \quad . \quad . \quad (31)$$

and there results, according to the

* Shäffer in his modification of Gerber's method has subsequently taken it into account. Deutsche Bauzeitung, 1877.

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theory, as mean stress per unit of section at the moment of buckling:

$$k_k = \frac{\delta EI}{Fl^2} = \frac{t}{\mu} \quad . \quad . \quad (32)$$

For the transmission of a pressure B_d there is required with a static load, without liability to buckling, a section $\frac{B_d}{t}$; with liability to buckling, a section $\frac{B_d}{t_k}$. In a sectional area F, the greatest stress per unit of area is without liability to buckling $\frac{B_d}{F}$.

Let k be the hypothetical stress per unit of area obtained on the supposition that the greatest stresses implied in (28) and (32) have the same ratio as the required sectional areas. Then

$$k : \frac{B_d}{F} = \frac{B_d}{t_k} : \frac{B_d}{t}.$$

Substituting from (32) there follows:

$$k = \frac{B_d}{F} \cdot \frac{t}{t_k} = \frac{\mu B_d}{F}.$$

This stress would be that due to a force equally distributed over the whole sectional area,

$$B_k = Fk = \mu = B_d \quad . \quad . \quad (33)$$

If B_k be substituted throughout in place of B_d, the same formulæ apply as without liability to buckling. The compressive force B_d, with liability to buckling, is equivalent to a compressive force B_k without liability to buckling.

The necessary sectional area on the assumption of a liability to buckling follows from (28)–(30):
for bars under compression only

$$F = \frac{B_k}{b} = \frac{\mu B_d}{b} = \mu F_d; \quad . \quad . \quad . \quad (34)$$

for alternations of tensile and compressive loads, B_t and B_d respectively:

$$\text{when } \mu B_d > B_t, F = \frac{B_k}{b} = \frac{\mu B_d}{v\left(1 - \frac{nB_t}{\mu B_d}\right)} \quad (35)$$

$$\text{when } \mu B_d < B_t, F = \frac{B_t}{b} = \frac{B_t}{v\left(1 - \frac{n\mu B_d}{B_t}\right)} \quad (36)$$

XIII. ANOTHER METHOD OF CONSIDERING THE LIABILITY TO BUCKLING.

The formulæ (34)–(36) derived from Navier's theory of buckling are only to be used for $\mu > 1$, as for $\mu < 1$ the calculation for uniform compressive stress only by (28)–(30) leads to greater sections. Hitherto in determining dimensions many engineers have been in the habit of combining the formulæ for uniform compressive stress and buckling, so that instead of writing in the one case without liability to buckling $Ft = B_d$ and in the other with liability to buckling $Ft = B_k = \mu B_d$, they introduced, generally, according to the practice of Rankine and Gordon,

$$Ft = (1+\mu)B_d, \; B_d = \frac{Ft}{1+\mu} \quad . \quad . \quad . \quad (37)$$

In an exactly corresponding manner the method of determining dimensions here under discussion may be proceeded with. Substitute, instead of in the one case B_d and in the other μB_d, generally, $(1+\mu)\,B_d$; whence instead of the formulæ (28)–30) applicable only for $\mu < 1$ and of those (34)–(36) admissible only for $\mu > 1$, the following formulæ, always applicable to bars under compression, with or without liability to buckling, appear:

for bars under compressive load only:

$$F = (1+\mu)F_d \quad . \quad . \quad . \quad (38)$$

for alterations of tensile and compressive loads B_t and B_d respectively:

$$\text{if } (1+\mu)B_d > B_t, F = \frac{(1+\mu)B_d}{v\left(1 - \frac{nB_t}{(1+\mu)B_d}\right)} \quad . \quad . \quad . \quad . \quad (39)$$

$$\text{if } (1+\mu)B_d < B_t, F = \frac{B_t}{v\left(1 - \frac{n(1+\mu)B_d}{B_t}\right)} \quad . \quad . \quad . \quad . \quad (40)$$

These equations resolve themselves for $\mu = 0$ into those applicable for simple compression only (28)–(30), and for μ very large as compared with 1 into the formulæ (34)–(36) derived from theory of buckling. They give larger sections than each of the corresponding others respectively.

XIV. ORDINARY PRACTICE WITH LIABILTY TO BUCKLING.

The method pursued in determining dimensions with reference to buckling will, in most cases, be the following:

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In the first place F_d is determined for simple compression only by (28)–(30), the section is provisionally arranged accordingly, μ is found by (31), and the formulæ (34)–(36) or (38)–(40) can then be applied.

The struts of bridges have usually a spread-out (*gespreizten*) section, and in most cases it will be found that $\mu<1$, so that for those who adopt Navier's buckling theory, and therefore the formulæ (34)–(36), no liability to buckling exists, and the values of F_d remain as the final sectional areas. Those, however, who have hitherto used the empirical formulæ (37) in determining dimensions, may, with equal propriety, apply the new method by means of the equations (38)–(40).

The increase of section from F_d to F, rendered necessary by the liability to buckling, may in struts of bridges be usually attained by a slight strengthening of their flanges. $\frac{I}{F}$ and $\frac{I_d}{F_d}$, where I_d is the value of I for the increased section, then differ so little that another calculation of F with the more accurate μ is superfluous, the more so as the coefficient σ is in no case very reliably determined.

This coefficient would be calculated for the various methods of securing the ends of struts with reference to the values of δ corresponding to the theory of buckling from (31). At the same time the theory does not agree particularly well with experience; and, in practice, ends absolutely rigidly fixed, or perfectly free to turn round the centers of their joints, by reason of frictionless articulation, do not actually occur. For iron bars with so-called fixed ends, the author is in the habit of making $\sigma=24{,}000$;* for iron bars with both ends secured by pins (American bridges) $\sigma=18{,}000$ has been given.†

For the other constants occurring in the preceding formulæ $v=700$, $m=n=\frac{1}{2}$.

XV. EXAMPLES.

Considering the simplicity of the method of determining dimensions here recommended, few examples are needed.*

Example 1.—The stress on a bar, normal to its cross section, varies between the tension 50,000 and the tension 20,000 kilogrammes. Required the admissible stress per square centimeter and the necessary sectional area.

$$\text{By (23) } b=700\left(1+\frac{1}{2}\cdot\frac{20{,}000}{50{,}000}\right)=340$$

kilogrammes per sq. centim.

$$F=\frac{50{,}000}{840}=59.52 \text{ square centimeters.}$$

Example 2.—The stress alternates, in a similar case, between the tension 40,000 and the compression 30,000 kilogs. The sectional area, without reference to buckling, is to be determined.

By (23)

$$F=\frac{40{,}000}{700\left(1-\frac{30{,}000}{2\times 40{,}000}\right)}=91.43 \text{ sq. centimeters.}$$

Where the admissible stress per square centimeter

$$b=700\left(1-\frac{30{,}000}{2\times 40{,}000}\right)=437.5 \text{ kilogrammes.}$$

Example 3.—What limiting stress per square centimeter should be chosen for the booms of a lattice girder when the ratio of the dead weight to the greatest total load amounts to $\frac{p}{q}=\frac{1}{3.5}$?

By (25)

$$b=700\left(1+\frac{1}{2\times 3.5}\right)=800 \text{ kilogrammes.}$$

With 640 instead of 700 it would be 745.

Example 4.—The load on a hollow cylindrical column varies between the compression $B_d=50{,}000$ and the compression $B_\delta=20{,}000$ kilogrammes. The sectional area for the length $l=400$ cen-

*For this values from 10,000 to 36,000 are in use. With E=2,000,000, and t=3,300 kils. per square centimeter, the theory gives, according to (31), σ=23,900. Later American experiments (Civilingeineur, 1878, pp. 17-28) lead with the assumption of formula (37) to a mean value 22,700.

†Prof. Cain in Van Nostrand's Eclectic Eng. Mag., 1877, p. 458.

*For further explanation for special structures, see Weyrauch, "Strength and Determination, &c.;" on the calculation of rivet joints, the same work; on the consideration of the liability to buckling Weyrauch, "Stabilita dele construzioni in ferro ed in acciaio;" on a special method of taking into account the shocks produced by the moving load, Zeitschr. d. Ostreich Ing. u. Arch. Vereins, 1879.

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timeters is to be calculated with reference to buckling.

From (28) or (23) or Example 1, where there is no liability to buckling, F_d = 59·52 square centimeters. Corresponding to this, the section is temporarily assumed as a ring of 10 centimeters outer, and 9 centimeters inner radius, whence follows F = 59.7, I = 2,700 centimeter-units. Equation (31) gives

$$\mu=\frac{59.7\times400^2}{2{,}700\times24{,}000}=0.15.$$

According to the theory there is therefore no liability to buckling, and the calculated section might be adhered to, since formula (34) leads to a smaller value. According to the empirical equations given in XIII., on the other hand, the choice would have to be

$$F = (1 + 0.15)\ 59.52 = 68.45$$

Square centimeters. This could be attained by keeping to the outer radius of 10 centimeters, by reducing the inner radius to 8.84, giving F = 68.6.

Example 5.—The stress on a strut in the web of a bridge girder alternates between the tension B_t = 40,000 and the compression B_d = 30,000 kilogrammes. The sectional area for the length l = 200 centimeters, with reference to buckling, is to be determined, the ends being fixed.

From (30) or (23), and as already shown in Example 2, without liability to buckling, F_d = 91·43 square centimeters. The strut is constructed in the manner of a plate girder, of four angle-irons, 8+ 8 + 1 centimeters, and a web 32+1 centimeters; whence F = 92 and the smallest moment of inertia of the cross section, I = 852 centimeter units. Formula (31) gives

$$\mu=\frac{92\times200^2}{852\times24{,}000}=0.18,$$

so that here, too, by the theory there is no liability to buckling. If, however, the empirical formulæ are to be used, then from (40), since $(1+\mu)\ B_d = 35400 < B_t$.

$$F=\frac{40{,}000}{700\left(1-\frac{35{,}400}{2\times40{,}000}\right)}=182.5\text{ sq. centim}$$

To make up this section the thickness of the angle irons may be assumed as 1.2 centimeter, and then F = 103.0 centimeters.

If the calculation were repeated with the more exact values of F and I, there would result consecutively I = 1028, μ = 0.17, F = 101.82. Consequently a value of F has been determined to small by 0.68 square centimeter = $\frac{2}{3}$ per cent. an error that may be neglected.

Example 6.—To calculate the strut given in the preceding example for the length l = 300 centimeters.

In this case the provisional values of F and I are exactly as above; on the other hand μ = 0.40, and since $(1+\mu)\ B_d = 42{,}000 > B_t$, by (39)

$$F=\frac{42{,}000}{700\left(1-\frac{40{,}000}{2\times42{,}000}\right)}=114.55\text{ sq. centim.}$$

XVI. Conclusion,

It is possible, as already indicated, to find many deficiencies in the method demonstrated. But, there are here only two questions for consideration; (1) Does the method lead to the expectation of greater security than that hitherto used in determining dimensions? (2) Is not another newer method to be preferred? In order to facilitate in the latter particular the judgment and independent choice of his English professional fellow-workers the author will be ready to give in a second Paper, a short explanation and comparison of all the methods hitherto proposed. His object is mainly to supersede the present method of determining dimensions. Even if it is thought that other formulæ for a and b should be preferred, the general principles here demonstrated may yet have contributed to the elucidation of the question.

Since the strength of materials has recently acquired a fresh interest, it may well be that at no distant time satisfactory relations that will admit of general application may be discovered. The author would welcome them with pleasure. It is sufficient for him to have contributed towards the supercession of the older method of determining dimensions so as to make way for a more rational system.

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THE AMOUNT OF RAINFALL IN ITS RELATION TO THE WATER SUPPLY OF A CITY.

By JULIUS W. ADAMS.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

AN article under the above heading appeared in the last number of the Magazine, upon which I would beg leave in the interests of the younger members of the profession, who consult your pages with profit, to make a few brief comments.

The true theory of any subject, must, of course, embrace all the facts known of it. Thus far we have too few facts upon which to build a comprehensive system—not to say—science of meteorology, and some time will elapse before we can pretend to reduce to rule the many anomolous phenomena attending the rain fall, and the resulting drainage from the water shed.

The writer of the article in question, after a review of the rain-producing processes over varied surfaces of the earth, and enumerating certain general principles which are presumed to affect the precipitation of moisture, takes the average annual rain fall in sections of the United States, and dividing these sections into nine groups, obtains what is characterized as a *type curve* for each group, representing the fluctuations of the monthly rain fall; and derives from the average rain fall of a series of years the factor 0.8, as representing the ratio of the rain fall for the dry years. Taking a twelfth of the annual rain fall for the monthly mean, he determines from the record of averages of the Atlantic coast stream flows, the ratio of the monthly flow of the streams to this mean as unity, and upon the *supposition* that 50 per cent. of the annual rain fall is collected in the streams, and 0.8 represents the ratio of a series of dry years to the mean annual rain, obtains a mean monthly rain fall, which combined with the monthly ratio of the flow of the streams above noted, gives the available flow in inches monthly, and adds—"which quantities have only to be multiplied by the number of acres or square miles in the water shed to determine the amount available." Subsequently, making an allowance of 60 per cent. for the annual evaporation from reservoir surfaces, and obtaining a monthly mean and ratio for this, finally embodies the whole in a table for use, "in the calculations upon water-works."

If the writer had confined himself to the phenomena attending the local rain fall, the deductions drawn would have been interesting to the extent of showing what had taken place, and what might be anticipated in the locality chosen—Troy for instance; but as he does not state explicitly, that his deductions are to be taken with great caution when used in estimating a city water supply, but if I understand the scope of the article, it is, that it offers a method by which, at least in the Atlantic States, and to the extent of 100 square miles of shed, the amount of water derivable from an estimate of the *mean annual* rains, may be used safely in estimating the water supply of cities. It is this which I take exception to—the application of any general formula for such purpose. However closely the results of using this method may approximate the truth in particular cases, as shown by existing works already established, and that it may do so is undoubted, yet it cannot be assumed, *a priori*, as applicable in the future for other localities. The whole principle of estimating from yearly averages of rain fall has been proven by experience to be misleading, and, for the purposes of a permanent city supply, no longer recommended.

Much misapprehension exists as to the amount of water which may be calculated upon with certainty on a given water shed; and disappointment in many notable cases, which might be cited, has arisen from taking as a standard for computation the average rainfall of a series

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of years. Even when a compensation is aimed at by large storage facilities, it is found to be impracticable to retain all the *average* counted on; as in the event of large floods occurring when the reservoirs are full, the water must be lost, and the available supply, obtainable from reservoirs, is found to fall short of that deduced from computations based upon average rainfalls. A single statement from the official report of the engineer of the Liverpool works will illustrate this. The average yearly fall for thirty years' observation showed 48 inches, and allowing 50 per cent. as collectable, 24 inches was assumed as available; with 3¾ million gallons per acre of the shed as storage room, 18 million gallons daily was estimated as the capacity of the works. (This was in addition to compensation water to certain mills.) Three dry years in succession reduced the delivery to six million gallons daily, or 9¾ inches instead of 24 inches over the entire shed. This case is but one of many bearing the same evidence.

Before a true average of rainfall can be determined upon in a given locality, of course the proper proportion of *dry* years should be embraced in the series, otherwise the estimate will be in excess —aside from the fact, that unless under exceptional circumstances, the minimum years of rainfall, and not the average become the true criterion for certainty of supply. And in addition to this, the year of least rain is not necessarily the year in which the season of least flow from the streams occur, and this latter is the measure of reliable supply. Nor is the year of least rainfall necessarily the year of drought, although frequently so; but the year of drought which tests the capacity of a city supply is the year wherein the rainfall is so unequally distributed, that for several months in succession, it may be, the evaporation and absorption and needs of vegetable life, take up all the rain which falls, and thus little or nothing is contributed to the city supply.

On the subject of evaporation from reservoir surfaces, it is manifestly an error to assume it as a percentage of the rainfall; for beyond the fact that during rains but little evaporation may be taking place, and at such times there may be a lowering of the temperature, which would tend to retard evaporation, there is nothing in a season of rain influencing to any extent such evaporation. Exposure to winds, hygrometric conditions of the atmosphere, the vicinity of forests or open plains, the presence or absence of elevated surroundings—all may effect it more or less, but independently of rainfall, and no connection necessarily exists between the two. The proper determination of the amount of evaporation from water surface is so replete with difficulties, and some of the results attained are thus far so anomalous, that the effort is no longer made to attain absolute accuracy in this respect; and it is assumed, in accordance with some observations, that the yearly rainfall on a given water surface, will supplement the loss by evaporation; hence, in considering the area of a gathering ground, if the water surfaces are subtracted in estimating the area of the shed, and disregarding the element of evaporation from these surfaces, it will be as near the truth as can be reached by any known method of observing evaporation. And so of the absorption of the soil, the demands of vegetation, and evaporation from ground surfaces, which are usually embraced under one head, can, neither collectively nor singly, bear any relation whatever to the amount of rainfall, and can only be approximately determined by long-continued observation and measurement on areas of similar characteristics, and the result deducted from the yearly rain, and independently of the extent of the latter. Neither of these items, any more than that of the evaporation from water surface, can be properly estimated as a percentage of the rainfall.

In the article referred to, reference is constantly made to the average annual rainfall as a basis for computation, and the low years precipitation is derived from it by the simple process of multiplying by 0.8; but unless the observations had extended through a greater number of years than is usual with such records in this country, and had certainly embraced a year or more of the *lowest* rainfall, or the season of lowest flow, it would scarcely prove a safe guide.

The flow from the Merimack, the Passaic, the Delaware, the Schuylkill and the Croton, as well as others of our

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rivers, may be computed on an average at one million of gallons daily throughout the year for every square mile of drainage area. But of what use is the knowledge of this fact, when it is equally certain, that save by an amount of storage room which is wholly impracticable, the freshet flows, which supplementing the low summer flow brings up the total to the average named, cannot be retained.

It is estimated that to avail of the average yearly flow of the Croton basin of 338 square miles, would require a storage of 41000 million gallons. This would accomplish it upon paper, but for obvious reasons, the reservoirs could not be counted on at all times to fulfill their purpose, were it practicable to build them; and hence a less discharge from the basin becomes the true measure of its capacity.

From 1864 to the present year, the average yearly rainfall on the Croton basin has been 46.1 inches. In the year 1877 the rainfall was so nearly the same (46.03) that the results of that year's observation are taken to represent the average. There was collected that year in the Croton, 45%, or 21 inches, as available rain, and the daily average flow for the year was a million gallons per square mile. Of the rain for that year, 15.8% was stored or used in the City of New York, 30.7% was lost for lack of storage capacity, and 53½% was evaporated from the surface of the shed (omitting the water surface) or absorbed, or used for vegetable life and did not reach the springs.

The rainfall the last year (1880) on the Croton shed was 38.5 inches; and the following represents the ratio of the several items of water supply for the several years named, on this basin and Ridgwood, L. I. In Blodgett's Climatology it appears that the Croton basin is credited with an average annual rain of 44 inches, and the Long Island basin with 42 inches. In the last 50 years the observations of the rain gauges have shown an average of 42.69 inches yearly rain, for the water-shed which supplies the City of Brooklyn.

	Years.	Square miles watershed.	Inches of rainfall.	Percentages of yearly rainfall.			
				Gathered in the streams.	Evaporated, absorbed and lost to the City supply.	Gathered, but lost for lack of storage.	Stored and used in the City.
Croton.....	1877	338	46.03	46.5	53.5	30.7	15.8
	1880	388	38.5	39.	61.	24.5	14.5
Brooklyn ..	1880	60	38.58	25.27	74.73	nothing.	25.27

It appears by the above, as might be anticipated, that the loss by evaporation and absorption, instead of being proportional in any degree directly to the amount of rainfall, is really inversely proportional thereto; and indeed an acquaintance with the detailed operations of almost any well-conducted city water supply, will show how little the *average* rainfall can be trusted as a safe guide, and the necessity which exists of referring, as of controlling importance, to those local characteristics, topographical and geological, as well as meteorological, which will be found to modify most materially the results arrived at by any general formula.

In a dry season the Croton basin has yielded a minimum of 100,000 gallons per square mile in twenty-four hours, and during the same season the Brooklyn basin has yielded a minimum of 300,000 gallons per square mile for the same time, the rainfall for the year being in favor of the Croton basin. This discrepancy in the amounts flowing from a given area, appearing within so short a distance as the width of the East River, will indicate to what extent local circumstances may influence the water supply of a city, independently of the extent of rainfall. Much has been written abroad upon this subject of water supply, but scarcely applicable to this latitude.

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ON THE VARIOUS MODES OF TRANSMISSION OF POWER TO A DISTANCE.

By M. A. ACHARD.

A Paper read before the Institution of Mechanical Engineers.

THE author in this paper furnished a summary of the practical results obtained in the transmission of power to a distance. While the interest attaching to this subject is unquestionable, the author is, nevertheless, very doubtful whether a successful result can be attained in one particular application—namely, the establishment of large undertakings for distributing hydraulic power to a number of factories, either existing or contemplated, similar to the undertakings at Schaffhausen, Fribourg, and Bellegarde. At the first of these places, in spite of favorable circumstances, rapid extension of working, and good management, the profit has been very small on the capital outlay. The manufactories at the two other places, being much less favorably situated, have failed after a short and profitless existence. Their failure has shown very clearly that their founders labored under a strange delusion in supposing that cheap motive power was in itself sufficient to create industries in localities where their essential elements were wanting. The author accordingly considers there is not much to be gained from this method of transmitting power to a distance, and that it can only succeed financially under exceptionally favorable conditions. Having promised so much, he next proceeded to examine the various methods used, or proposed, for transmitting power to a distance. He first considered transmission of power by wire ropes, which is merely an extension of the simple case of transmission by ordinary hemp ropes, and the same principles apply to both. Let A and B be the axes of two parallel shafts carrying two pulleys whose planes coincide. The driving power P acts on A, and the resistance Q on B. For simplicity, let it be assumed that those two forces act tangentially at the circumference of the pulleys. The motion is communicated from A to B by means of the rope passing round the two pulleys; of this the part which is passing towards the driving pulley is called the driving span, and the part which is passing from the driving pulley is called the trailing span. Let T be the tension of the driving span, and t that of the trailing span. Neglecting friction, &c., we should have Q=P; and the values of the tensions in the two spans are given by the equations

$$T-t=P \text{ and } \frac{T}{t}=k;$$

denoting by k the smallest practicable value of e^{fa} for the two pulleys, where e is the base of Napierian logarithms, f the coefficient of friction between the pulley and the rope, and a the ratio between the arc encircled by the rope and the radius of the pulley. Accordingly the values of T and t are given by the following equations:—

$$T=\frac{k}{k-1}\frac{P}{}; \quad t=\frac{P}{k-1}.$$

If the ratio $\frac{T}{t}$ be greater than k, the rope will slip on the driving pulley. The values of T and t, as above calculated, when k has its exact value, are only just sufficient to prevent slipping, which would occur on any accidental diminution of friction. For safety, therefore, it is necessary to assign to k a somewhat lower value than its real one; which practically amounts to increasing the tensions T and t a little beyond what is requisite in theory. The tension common to the whole rope when at rest is somewhere intermediate between the tensions T and t of its two spans while running; and by adjusting the rope while at rest to this intermediate tension, its two spans assume of their own accord the required tensions T and t as soon as it begins to run. The section w to be given to the rope, so that it may possess the requisite strength, is regulated by

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the driving tension T, and must be such that the quotient $\frac{T}{vo}$ shall not exceed the working strain which the material of the rope is suited to bear in practice. It is evident that, in transmitting a given amount of power, the driving tension, and consequently the section of the rope, may be diminished by increasing the speed; for if N denotes the power transmitted, and v the speed of the rope, then

$$Pv=N, \text{ and } T=\frac{kP}{k-1}=\frac{k}{k-1}\ \frac{N}{v}.$$

In practice the rope elongates under the continuous pull, and requires shortening from time to time to keep the tension up to the proper amount. The author next took into account the useless resistances neglected for the sake of simplicity. The useful resistance Q is now necessarily less than the driving power P, and the ratio $\frac{Q}{P}$ represents the efficiency of the transmission. The useless resistances are two in number. The first is the rigidity or stiffness, due to the imperfect flexibility of the rope. This effect, however, is insignificant in the case of rope transmission, on account of the large size of the pulleys employed. The other useless resistance is the friction of the two shafts A and B in their bearings, which is measured by the resultant F of all the external forces acting on each shaft. It appears from the principles enunciated above that the employment of rope transmission renders this friction considerable. In fact, under average conditions of adhesion, the value to be allowed for $k=e^{fa}$ is not more than 2; and since in the limit

$$\frac{T}{t}=k \text{ and } T=\frac{kP}{k-1},$$

we have as the least possible values T=2 P, and t=P. These tensions are parallel to each other, and as the useful resistance Q may also act in the same direction, the total pressure F on the shaft may=T+t+P=4 P, as a minimum, where the conditions are the most unfavorable; while under the most favorable conditions the pressure on the bearings will be given by F=T+t−P=2 P, as a minimum. Hence the average pressure may be taken as at least 3 P. It is evident, therefore, that rope transmission renders the shaft friction much greater than does transmission by toothed wheels. But the effect of this friction is much reduced by the large diameter of the pulleys in comparison with that of their shafts, in consequence of which the pressure on the shaft bearings, has to be multiplied by a number not exceeding at most 0.003, in order to obtain the resulting tension on the rope. The author dealt briefly with belting and went on to consider at length the nature of the strains to which ropes are subject. It is difficult to lay down any general rule as to the duration of the ropes, for this depends upon the conditions under which they work. In practice, it must not be assumed that a rope in constant use will last more than a year. In fact, Professor Amsler-Laffon recently wrote to the author on the subject of the ropes at Schaffhausen:—"A rope lasts about one year, some a little more, some a little less. But it must be understood that we do not wait till our ropes break, but replace them as soon as we can no longer depend on their strength. They might therefore last rather longer, if we chose to run the risk of interruption in our work." Their short life is certainly a defect in this mode of transmitting power. According to M. Ziegler, who has considerable experience on this subject, horizontal oscillations are very injurious to the duration of the ropes, and they appear to last longer on pulleys with wide grooves than with narrow grooves. The author next considered transmission by compressed air. Hitherto the method of transmission by compressed air has only been used, so far as the author is aware, for boring the headings of mines, and the long tunnels through the Alps. In these cases, as is well known, the work to be done consists in a rapid boring of holes for the purpose of blasting the rock with powder or dynamite. As this kind of work requires a high pressure of air, and almost entirely precludes the employment of expansion, the utilization of the motive force is necessarily defective; but in consequence of the peculiar convenience which compressed air offers for the work, and particularly the improved ventilation which it affords, the advantage of its employment is un-

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doubted, and leaves in the background the question of efficiency. M. Achard dealt at great length with the somewhat complex mathematics of the subject, but he did not supply much if any new data. Referring to the motors fed with the compressed air, the author held that this subject is still in its infancy from a practical point of view. In proportion as the air becomes hot by compression, so it cools by expansion, if the vessel containing it is impermeable to heat. Under these conditions, it gives out, in expanding, a power appreciably less than if it retained its original temperature, besides which the fall of temperature may impede the working of the machine, by freezing the vapor of water contained in the air. If it is desired to utilize to the utmost the force stored up in the compressed air, it is necessary to endeavor to supply heat to the air during expansion, so as to keep its temperature constant. It would be possible to attain this object by the same means which prevent heating from compression, namely, by the circulation and injection of water. It would, perhaps, be necessary to employ a little larger quantity of water for injection, as the water, instead of acting by virtue both of its heat of vaporization and of its specific heat, can in this case act only by virtue of the latter. These methods might be employed without difficulty for air machines of some size. It would be more difficult to apply them to small household machines, in which simplicity is an essential element; and we must rest satisfied with imperfect methods, such as proximity to a stove, or the immersion of a cylinder in a tank of water. Consequently, loss of power by cooling and by incomplete expansion cannot be avoided. The only way to diminish the relative amount of this loss is to employ compressed air at a pressure not exceeding three or four atmospheres. The only real practical advance made in this matter is M. Mekarski's compressed air engine for tramways. In this engine the air is made to pass through a small boiler, containing water at a temperature of about 120 deg. Cent.—248 deg. Fah.—before entering the cylinder of the engine. It must be observed that in order to reduce the size of the reservoirs, which are carried on the locomotive, the air inside them must be very highly compressed, and that in going from the reservoir into the cylinder it passes through a reducing valve, or expander, which keeps the pressure of admission at a definite figure, so that the locomotive can continue working so long as the supply of air contained in the reservoir has not come down to this limiting pressure. The air does not pass the expander until after it has gone through the boiler already mentioned. Therefore, if the temperature which it assumes in the boiler is 100 deg. Cent.—212 deg. Fah.—and if the limiting pressure is five atmospheres, the gas which enters the engine will be a mixture of air and water vapor at 100 deg. Cent.; and of its total pressure the vapor of water will contribute one atmosphere, and the air four atmospheres. Thus this contrivance, by a small expenditure of fuel, enables the air to act expansively without injurious cooling, and even reduces the consumption of compressed air, to an extent which compensates for part of the loss of power arising from the preliminary expansion which the air experiences, before its admission into the engine. This scheme was then mathematically investigated by the author. Next M. Achard dealt with the transmission of power by water pressure. Of machines worked by water pressure, the author referred only to two, which appear to him in every respect the most practical and advantageous. One is the well-known piston machine of M. Albert Schmid, engineer, Zurich. The cylinder is oscillating, and the distribution is effected, without an eccentric, by the relative motion of two curved surfaces fitted one against the other, and having the axis of oscillation for a common axis. The convex surface, which is movable and forms part of the cylinder, serves as a port face, and has two ports in it communicating with the two ends of the cylinder. The concave surface, which is fixed and plays the part of a slide valve, contains three openings, the two outer ones serving to admit the pressure water, and the middle one to discharge the water after it has exerted its pressure. The piston has no packing; its surface of contact has two circumferential grooves, which produce a sort of water packing acting by adhesion. A small air chamber is connected with

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the inlet pipe, and serves to deaden the shocks. This engine is often made with two cylinders, having their cranks at right angles. Its efficiency is equal to from 37 to 83 per cent. The other engine, which is much less used, is a turbine on Girard's system, with a horizontal axis and partial admission, exactly resembling in minature those which work in the hydraulic factory of St. Maur, near Paris. The water is introduced by means of a distributor, which is fitted in the interior of the turbine chamber, and occupies a certain portion of its circumference. This turbine has a lower efficiency than Schmid's machine, and is less suitable for high pressures; but it possesses this advantage over it—that by regulating the amount of opening of the distributor, and consequently the quantity of water admitted, the force can be altered without altering the velocity of rotation. Its efficiency varies between 35 and 68 per cent. The transmission of power by electricity was considered last of all. The author stated nothing new on this subject. He gave a table by Mr. Hagenbach, which promised to be useful, but he added that the brake measurements obtained were inaccurate, consequently the table is of little value. He concluded his paper with a retrospective glance at the four methods of transmission of power which had been examined. It would appear that transmission by ropes forms a class by itself, whilst the three other methods combine into a natural group, because they possess a character in common of the greatest importance. It may be said that all three involve a temporary transformation of the mechanical power to be utilized into potential energy. Also in each of these methods the efficiency of transmission is the product of three factors or partial efficiencies which correspond exactly—namely, (1) the efficiency of the instrument which converts the actual energy of the prime mover into potential energy; (2) the efficiency of the instrument which reconverts this potential energy into actual energy, that is into motion, and delivers it up in this shape for the actual operations which accomplish industrial work; (3) the efficiency of the intermediate agency which serves for the conveyance of potential energy from the first instrument to the second. This last factor for transmission by electricity is the exact correlative of the efficiency of the pipe in the case of compressed air, or of water pressure. It is as useful in the case of electric transmission, as of any other method, to be able, in studying the system, to estimate beforehand what results it is able to furnish; and for this purpose it is necessary to calculate exactly the factors which compose the efficiency. In order to obtain this desirable knowledge, the author considers that the three following points should form the aim of experimentalists: (1) The determination of the efficiency K of the principal kinds of magneto-electric, or dynamo-electric machines working as generators. (2) The determination of the efficiency K, of the same machines working as motors. (3) The determination of the law according to which the magnetism of the cores of these machines varies with the intensity of the current. The author added that he would gladly have concluded this paper with a comparison of the efficiencies of the four systems which have been examined, or, what amounts to the same thing, with a comparison of the losses of power which they occasion. Unfortunately such a comparison has never been made experimentally, because hitherto the opportunity of doing it in a demonstrative manner has been wanting; for the transmission of power to a distance belongs rather to the future than to the present time. The author believes that transmission by ropes furnishes the highest proportion of useful work; but that as regards a wide distribution of the transmitted power the other two methods, by air and water, might merit a preference.

The discussion which followed, the author being absent, was opened by Mr. J. N. Shoolbred, who gave facts and set forth certain experiments on the efficiency of electric generators, quoted in the paper, in a form more in accordance with English ideas. He observed that they confirmed the previous experiments of Dr. Hopkinson and others as to the very high efficiency of such generators, but this of course proved nothing as to the efficiency of transmission by electricity, where the electricity, after being generated, had to be reconverted into

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power at the other end. In this reconversion Dr. Siemens' experiments showed a loss of about 50 per cent. Recent experiments of his own, however, led to the hope that this loss might be largely reduced by adopting proper precautions between the two machines, the generator and the motor. Anyhow, there were many ases where efficiency was of the first importance, *e. g.*, where natural sources were utilized, or a large central steam engine could be drawn upon, &c., and here the greater compactness and economy of the electric transmission would give it important advantages. Mr. Alexander Siemens followed in the same strain, and thought far too much was made of the question of efficiency, which was often of little importance. He instanced Sir William Armstrong's arrangement at Rothbury, and that of Dr. Siemens at Tunbridge; and looked forward to the time when large steam engines would be established at central positions in towns, whence the power would be distributed by electricity as required. He held that a few experiments were necessary to settle the arrangements of such transmissions, be cause the conditions might always be preserved constant, by arranging the proper resistance in the leading wire; and considered that prejudice was now the only thing that hampered the transmission of power by electric means.

Mr. Fernie recalled the attention of the meeting from electricity, and gave some examples of the extensive use of transmitted water power in Switzerland. He mentioned that in Geneva the men who cut firewood for house use used small machines, which they worked by attaching them to high-pressure mains laid along the streets. M. Schönheyder then drew attention to a statement in the paper with regard to the wide belts used in America—viz., that at high speeds a partial vacuum is formed between the belt and the pulley, which gives an adhesion more like that of an ordinary leather sucker, and greatly increases the tension which the belt will bear without slipping. M. Schönheyder altogether disbelieved in the existence of this action—and probably with justice—though it has undoubtedly been claimed in the case of American belts. He discussed the reason why the iron ropes used in the transmission wore so rapidly, lasting, *e.g.*, at Schaffhausen, only twelve months; and suggested that they must either be drawn too tight, or given too high a working strain. He also spoke of the great friction of water in pipes under heavy pressure, examples of which were given in the paper; and suggested that further experiments were desirable on this subject. Mr. W. E. Rich took up a point neglected in the paper, viz., the proper pressure to be used in transmission by compressed air. This, he held, should be as low as was convenient, say, 30 lbs. per square inch, for dry air compressors. Air compression he considered was better suited to intermittent than constant transmission. In the latter case the freezing at the exhaust ports was a great inconvenience, but this might be remedied by placing a small fire near them, or otherwise. With regard to water engines, the greatest inconvenience was the slide valve, which always gave trouble, and should be done away with if possible, a result already attained in Mr. H. Davey's water engines, described by him to the Institution in 1880.

REPORTS OF ENGINEERING SOCIETIES.

THE AMERICAN SOCIETY OF CIVIL ENGINEERS.—The Society have of late engaged in the discussion of the question of wind pressure on Bridges. Paper No. 213, by C. Shaler Smith, gave some interesting and valuable observations bearing on this question.

The following is an abstract from it:

For a number of years past, whenever practicable, I have personally visited the tracks of destructive storms as soon as possible after their occurrence, for the purpose of determining the maximun force and width of the path in each case.

The most violent on my records are as follows:

First.—East St. Louis, 1871: Locomotive overturned; maximum force required, 93 lbs. per square foot.

Second.—St. Charles, 1877: Jail destroyed; force required, 84.3 lbs. per square foot.

Third.—Marshfield, Mo., 1880: Brick mansion house leveled; force required, 58 lbs. per square foot.

Fourth.—Havre de Grace, Md., 1866: Ten spans wooden Howe truss bridge, 250 feet each, blown over; force required, 27 lbs. per square foot.

Fifth.—Decatur, Alabama, 1870: Two spans of Combination Triangular truss blown over; force required, 26 lbs. per square foot.

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Sixth.—Meredosia, Ill., 1880: One span wooden Howe truss, 150 feet long, overturned; force, 24 lbs. per foot.

Seventh.—Omaha, Nebraska, 1877: Two spans iron Post truss, 250 feet each, blown down; force required, $18\frac{7}{10}$ lbs. per square foot.

Also, sundry cases of train derailment caused by wind, the maximum force required being 30½ lbs. per squre foot.

In each of the foregoing cases I have given what appeared to be the maximum effort of the wind and the lowest pressure required to produce the observed result. It is therefore not unlikely that the real force of the wind in each example was greater than I have given it. Some of the tornadoes were very destructive—the Marshfield one, for instance, having cut a swath 46 miles long and 1800 feet wide, and killed and wounded over 250 people. To the above cited instances may be added the Tay Bridge disaster, in which case $20\frac{4}{10}$ lbs. per square foot on train and bridge were required to destroy the piers, through the rupture of the vertical bracing in the four bottom tiers of the pier, over which the train was passing when failure began. My reasons for considering 30 lbs. per square foot sufficient for a working specification, when the above record shows much higher pressures, are these—

First.—I very much doubt if a *direct* wind or gale ever exceeds 30 lbs. per foot; whirlwinds do exceed it, but the width of the pathway of maximum effort in these is usually very narrow, although the general direction is so erratic that the appearance of the *debris* is generally such as to produce the impression that the vortex was much larger than was really the case. With the exception of the Marshfield tornado, I have yet to find a storm swath where the width of pathway, wherein the force exceeded 30 lbs. per square foot, was more that 60 feet wide.

The St. Charles tornado is a case in point. This whirlwind cut a swath about 1000 feet wide for 14 miles, and destroyed over 300 houses, exerting a force of over 84 lbs. per square foot at its point of maximum effort. It crossed the middle span of the St. Charles bridge nearly at right angles, and developed a pressure of $52\frac{4}{10}$ lbs. per square foot in picking up and crushing a barrel of tar, which stood on the bridge in the path of the vortex. The width of the vortex was distinctly marked on the span by the circle in which the tar was spun around, the wreckage left upon it, and the points at which it ceased to destroy the flooring. This width was thus shown to be slightly over 60 feet, and, guided by this, I was subsequently enabled to locate the path traveled by the central vortex throughout the entire length of the storm swath. The bridge itself was uninjured, although it was only proportioned to withstand 30 lbs. per square foot, with a strain of 20,000 lbs. per square inch on the braces. This span was 320 feet long, 30 feet in depth, and the top chord was 120 feet above the water. I consider it very unlikely that a bridge of over 200 feet span will ever be exposed to a wind force of more than 30 lbs. per square foot, acting *in the same direction* over its entire length.

Next.—A fully loaded passenger train, and the heaviest possible freight train will leave the track at the respective pressures of 81¼ and 56½ lbs. per square foot. If the braces are proportioned at 15,000 lbs. per square inch, with a wind pressure of 30 lbs. per square foot, they will still be within their limit of elasticity at the moment when the train is blown from the track in either case. Destruction of the span will then take place, if at all, from the effects of derailment; to resist which greater strength in the wind bracing will be of no value.

Next.—If there is no tension in the pier columns until 30 lbs. wind pressure is reached, and these columns are properly spliced and anchored, as per specifications, there will be an ample margin of tensile strength in any case where this pressure may be exceeded.

Last.—In view of the comparative rarity of these extreme strains and the consequent slight fatigue to which the iron is exposed, the high stresses imposed on the wind bracing are perfectly legitimate.

BOSTON SOCIETY OF CIVIL ENGINEERS.—At the regular February meeting, a paper on "The Fall River Bridge," prepared by the late E. N. Winslow, was read by the Secretary.

The committee to whom was referred the subject of issuing a work on the "Law and Practice for Land Surveyors in the New England States," reported adversely.

At the February meeting a paper on "Railroad Signals" was read by George W. Blodgett.

The committee on the Metric System reported on the information obtained relative to the progress toward introduction of the system into this country and the world at large.

POLYTECHINIC CLUB OF THE AMERICAN INSTITUTE.—The paper of the evening, February 24, was upon the subject of scientific books, by Mr. Wm. H. Farrington, of the house of D. Van Nostrand. It was an elaborate discussion of the subject, and was full of the most interesting information.

The noticeable feature of modern scientific literature is the tendency to give science an every-day dress, and to describe many of the most ordinary vocations from a scientific standpoint.

At the present time at least ten divisions are needed in order to reasonably classify scientific books. The last of them, the so-called "Popular Science," attempts to draw into itself all the forms and phases of modern scientific literature.

In all languages, especially English, French and German, works bearing upon construction take prominent places, and in this term "construction" it is intended to embrace steam engineering, railway science, building, &c. The engineering books easily take the foremost rank among the works of science.

One of the earliest leading publishers of scientific books, and one who in his day made this class of literature a representative one,

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was John Weale, of London. We all know, I presume, what the "Weale's Series" are—the little green or red covered books, in limp or flexible cloth, with flush cut edges. Mr. Weale has been dead many years, but his series of reasonably-priced scientific treatises upon all manner of subjects still lives. It is true the advancements science has made has rendered necessary many changes in these little books; some have been rewritten and enlarged and altered as they have passed down through different publishers' hands; their number has been added to, until there are now about 200 of them, and they have had a sale of many thousands and continue to sell. To a considerable extent engineering science is predominant in this series, but they cover a wide range of other subjects. No attempt has been made to emulate this series of Weale, unless we might mention in connection with it the "Roret Manuals" and the more recent "Actualities Scientifiques," and the "Science Series," of Van Nostrand, New York, begun a few years ago.

The first named of these is—or, rather, was—a very popular series in the French language, of compact little volumes upon technology, or the science of the workshop, and were largely embraced within the domain of applied chemistry. The "Actualities Scientifiques" of Mallet-Bachelier, Paris, are no more popular than the "Weale's Series," but cover a rather wider range of subjects, and are strictly less scientific, while for Van Nostrand's we can only say, that so far as the higher branches of science are concerned, they would take precedence of all, but as individual treatises are much less exhaustive of the subject, and in many instances partake more of the character of a monograph on some special branch. Some of Mr. Weale's other publications, such as his collections of plans and drawings of bridges, with descriptive text, his large and exhaustive works upon the "Steam Engine" and on "Railways," his fine volumes on "Architecture," his "Quarterly Papers on Engineering," and another series in the same style on "Architecture," while expensive as books, are remarkable examples of scientific literature, and remain as monuments to the man John Weale more enduring than brass or stone

The relatively high price of scientific works was spoken of at length, and the reasons for it pointed out. These were the comparatively small editions which can be sold, and the greater expense entailed in the original preparation of the work. Tabulated work, algebraic formula, with cuts and diagrams, largely increase the expenses of production. In England, publishers of scientific books do not, as a rule, electrotype their works, preferring, when an edition is exhausted, to prepare a revised edition. In this country electrotyping is the rule, hence different editions are brought out with only trifling variations.

It is a noticeable fact that Rankine's works, though of the highest character—one might almost say abstruse—have had a large and steady sale in this country. This is a fact that, to say the least, speaks well for the ability of our students.

There are constant calls for books upon subjects which are treated of in the larger and more expensive technical cyclopedias. That these demands are not supplied, is largely due to the fact that in many cases the works would of necessity be filled with trade secrets.

Some of the notable scientific books were described and their curious histories given. Among others the growth of Weisbach's "Mechanics" was traced, and its curious continual publication in parts in Germany mentioned. In conclusion, Mr. Farrington said:

"Regarding the publishing houses of scientific books, I would state that in England two only confine themselves exclusively to this line—E. & F. N. Spon, and Crosby Lockwood & Co. Many other houses, as in this country, publish various works in science of all kinds, and are heavy publishers as well, such as Longmans & Co., London, or Appleton & Co., here; but Spon and Lockwood confine themselves now to science only, and the former house deals mostly in engineering and the allied sciences. Lockwoods are now the publishers of Weale's series and many other important and elaborate works. In Paris, Mallet-Bachelier, Lacroix and Dunod are the leading houses, the former, successor to Gautier-Villars, deal mostly in mathematical books, and the latter mainly in engineering, architectural and hydraulic works. Recently they have issued an exhaustive series on engineering in all branches. Dubauve's "Manuel de l'Ingénieur" in 20 octavo volumes and 12 quarto atlases of plates. Dumain of Paris confines himself to military literature exclusively. In this country the leading publishers in science alone are H. C. Baird & Co., of Philadelphia, and Van Nostrand and John Wiley & Sons, of this city. The former house publishes books of an exclusively practical nature, or, as they term it, "Industrial Science." Van Nostrand, on the other hand, has more of the theoretical class on his list, and also combines with these military and naval science. The Messrs. Wiley have never confined themselves solely to science, They are possibly doing so more of late, but still they deal in some miscellaneous literature, as well as in biblical.

Large numbers of publishers, however, throughout the country are turning their attention to works in science, and the number of books issued are increasing year by year. The proportion of scientific works published in this country, however, to the whole number in other branches of literature, is relatively small, and, in comparison to what the Germans and French are giving to the world, would seem quite insignificant. In closing these remarks, I would like to say that now that the apprentice system has been virtually abandoned, young men, who are learning a trade, have to depend largely upon their own studiousness to become proficient in their line of work. To this end these books, of which I have been speaking, are the essential helps, and I really think that, with the array of volumes presented, little excuse exists for any conscientious workman to remain in ignorance of the requirements of the trade of his choice, or fail to attain a fair proficiency in it.

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ENGINEERING NOTES

ON A ROPE TRAMWAY AT STRASBURG.—(From abstracts of Inst. of Civil Engineers) —This tramway is in use at Strasburg for removing the earth from a ditch, 22 feet deep, forming part of the new system of fortifications. Starting from the lowest point of the excavation, it is carried first through a short tunnel at a rise of 1 in 10, then passes over a railway (which is protected by a temporary roofing) and thence is led horizontally to its farther or discharging end, the total length being about 1,000 yards. A peculiarity of the system is that the roads, as they may be termed, on which the skips of earth travel are not of wire rope, as usual, but of round bar iron. Of these there are two lengths, 5 feet 9 inches apart—one having a diameter of 1¼ inch for the loaded skips, and the other having a diameter of 1.02 inch for the empty ones. They are welded up into lengths of about 55 yards, and these lengths are afterwards united by steel couplings, having a diameter as little differing from their own as possible. These "roads" are anchored down to the ground at the loading end, but at the other end terminate in chains which pass over pulleys and support hanging weights, sufficient to bring a strain of 4½ tons on the stronger "road," and 3½ tons on the weaker. There are forty intermediate supports of timber (some of them above 100 yards apart), carrying at the top small grooved pulleys on which the rope actually rests. The skips are made entirely of wrought iron, much like a dredger bucket. They weigh about 290 lbs , and carry 8½ cubic feet, the total weight transported being thus about 1,000 lbs. They are hung on gudgeons, and empty themselves by turning over as soon as a single fastening is loosened. There are special mechanical arrangements for connecting the hanging skip with a small frame above, carrying two wheels which travel on the fixed "road." The whole is connected with a running endless wire rope which communicates the motion. It is ¾ inch in diameter, is driven by a portable engine at the loading end, and is kept taut by passing round a counterweighted sheave of 5 feet 9 inches diameter, capable of traveling upon cast iron guides. The speed of the running rope is in general about 4 feet per second. Small steel couplings are fixed on it at intervals of 130 feet, and to these the successive skips are attached—the mechanism both for attaching and disengaging being self-acting. At the discharging end there is an apparatus of iron rails for transferring the skips from one road to the other; by making this portable and providing it with supports it is further utilized for shifting the ends of the tramway and the point of loading so as to follow the progress of the excavation. With the speed of rope and distance between skips given above the quantity of earth conveyed is about 40 cubic yards per hour. The changing of the skips at the loading point (and similarly at the discharging point) is managed by a single workman. Each empty skip, as it comes upon the return road, detaches itself just before it reaches the workman, who receives and pushes it on to one of the lines of rails leading to the face of the excavation. He has already put in position a full skip which has just arrived by the other line of rails; and the same coupling which has conveyed the empty skip picks up the full skip in passing, attaches it to the rope and takes it away along the tramway. Thus the whole number of men employed on the tramway, as apart from the excavation, is only six at the most. The engine employed is of 8 HP., but 2 to 3 HP. is found to be all that is required for the work. The laying down of the tramway was completed, though in the depth of winter, in less than ten weeks; and Herr Bleichert, the inventor, states that he has tramways at work on this system which are 2,400 yards long, with gradients of 1 in 3½, and conveying earth to the extent of 500 cubic yard per day.—*Deutsche Bauzeitung.*

SWISS TRIANGULATION.—The operations in the neighborhood of Aarlberg, under the direction of the Spanish General Ibanez, for measuring the base of the network of Swiss triangulation, have been very satisfactory. The base has been measured twice. The result of the first measurement was 2400.087 meters (1.502 miles); the second operation, which was conducted entirely independently of the first, for the purpose of verification, gave 2400.085 meters. The difference between the two measurements was only two millimeters, or less than one ten-thousandth of one per cent. The place chosen for the base is on the route of Sisselen, where a perfectly straight and nearly horizontal line may be drawn for a distance of about three kilometers (1.864 miles). Similar measurements are to be made in the valleys of Tessin and of the Rhine.

THE SUEZ CANAL TONNAGE—Of a total of 3,446,431 tons gross of shipping that passed through the Suez Canal in 1880, the share of England was 3,446,431 tons, or more than three-fourths of the whole. The increase, compared with 1879, was from 2,508 524 English, and a total of 3,236,942 tons. Next to England the most marked augmentation was that of the Russian flag, which rose from 8799 tons to 45,899 tons. French tonnage remained almost stationary, having only advanced from 262,017 tons to 271,598. German rose from 21,548 to 52,551; Austrian, from 51,400 to 103,030; Spanish, from 64,468 to 84,519; Italian, from 94,162 to 104,567; and Dutch from 159,024 to 174,485. All the principal countries of Europe shared in the improved trade with the East in 1880.

IRON AND STEEL NOTES.

A GREAT CRUCIBLE STEEL CASTING.—During the past week Messrs. Jessop & Sons, Brightside Steelworks, Sheffield, cast the largest crucible steel casting that has yet been produced. It is a spur ring 28 feet in diameter, machine moulded, and cast whole. To cast it 270 pots were used, each pot holding 80 pounds weight of molten steel. When the

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steel had been poured into the three large ladles, the plugs were removed, and it ran into the mould, the weight when cast being about 10 tons. In its finished state the weight will be about 8½ tons. It is, without doubt, by far the largest crucible cast steel casting of its kind that has ever been produced. Messrs. Jessop & Sons anticipate that this will be the beginning of an important trade with Lancashire millowners, as they discover how much more durable steel wheels are than the cast-iron wheels at present in general use. The firm have previously cast wheels 13 feet and 14 feet in diameter, but to 28 feet was a great leap. Now, however, they are prepared to undertake castings up to 34 feet, having gone to very great expense in laying themselves out for this class of work. The operation of casting occupied eight and a-half minutes.

BESSEMER STEEL IN THE UNITED STATES.—The total production of Bessemer steel during last year, at the eleven works in the United States, during the year 1880, indicates an unusual amount of activity. The amount of steel manufactured in 1880 was 1,203,178 tons (2000 lbs.) showing an increase of 30 per cent. as compared with 1879; of 64 per cent. compared with 1878, and 115 per cent. compared with 1877. The annexed table shows the annual production of Bessemer steel in the United States since 1872:

Year.	Tons.	Year.	Tons.	Year.	Tons.
1872	120,108	1875	375,517	1878	732,226
1873	170,652	1876	525,996	1879	928,972
1874	191,933	1877	560,587	1880	1,203,178

During the year, the eleven companies produced a total of 917,592 tons (2000 lbs.) of steel rails, and the development of this manufacture will be seen from the following table, which corresponds to the one above:

Year.	Tons.	Year.	Tons.	Year.	Tons.
1872	94,070	1875	290,863	1878	550,398
1873	129,015	1876	412,461	1879	683,964
1874	144,944	1877	432,169	1880	917,592

Startling as this growth of production is, it will undoubtedly be surpassed by the output of the present year, for not only does the demand continue in the United States, but several of the more important works materially enlarged their capacities last year; the Vulcan Steel Works at St. Louis got into working order only in March last, so that it contributed to the total only during nine months; the Pittsburgh Bessemer Steel Company, with a capacity of 60,000 tons of ingots a year, are just on the point of commencing work; and the Colorado Coal and Iron Company will be in operatowards the autumn.

AT a meeting of the Chemical Society on the 20th ult., a paper was read on a "New Theory of the Conversion of Bar Iron into Steel by the Cementation Process." by Mr. R. Sydney Marsden, D. Sc. The author first referred to a former paper of his in the "Proceedings" of the Royal Society of Edinburgh, Vol. X., p. 712, in which he had shown that when amorphous carbon in an impalpable powder is kept in contact with porcelain at a temperature considerable above redness, but not sufficient for the latter to become fused, the carbon will, if left for a number of hours, diffuse into the porcelain and ultimately permeate it throughout. He considers the conversion of bar iron into steel by the cementation process as analogous to this—that is to say, the result of diffusion of carbon in an impalpable powder into the bars of iron whilst they are in an expanded and softened state. Silicon also appears to be present in the amorphous condition, and to diffuse through iron in a similar manner.

RAILWAY NOTES.

MASSACHUSETTS RAILROADS.—From the Report of the Railroad Commissioners we learn that the aggregate length of the railroads belonging to corporations making returns to the Board is 2667.35 miles, of which 651.48 miles are provided with double track. The total length of track, counting sidings and branches, is 4257.78 miles. The increase during the year being 107.79 miles.

The average cost of standard gauge roads is returned at $57,057.80 per mile, and the cost of equipment averages $6613.90 per mile, making total cost per mile an average of $63,671.70; but this cost varies from $24,353.25 to $92,068.30. The average cost of the equipped narrow gauge roads is $31,293.30.

The gross income for the year, of the sixty-four corporations, was $35,140,374.77, and the net income $11,191,815.53, a gain of 10 per cent. over last year.

The average earning per mile of road was $11,377.90. For the eight roads terminating in Boston the earning per mile averaged $12,079.70.

DURING the early part of last year the total length of the Prussian railway system was 6197 kilometers, including 798 which had been added in the course of the year. By the end of the year the length had been increased to 6299 kilometers. The cost of the whole system had been 1,493,305,418 marks—£74,665,270—or at the rate of 244,312 marks per kilometer. The receipts for the year were 163,877,969 marks as against 155,881,124 in the previous year. There was, however, a diminution of receipts per kilometer from 29,582 marks to 26,580, or at the rate of 9 per cent.; though, on the other hand, the expenditure also decreased from 18,042 to 16,326 marks per kilometer, or 9½ per cent. The general result shows an excess of receipts over expenditure of 61,826,748 marks, against 57,990,555 in the year before.

IN accordance with the provisions of the Berlin Treaty, the Railway Commission appointed to deal with the new lines of the southeast of Europe will assemble in Vienna for the despatch of business in the second half

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of February. The Bosnia Valley Railway Bill has passed the Upper Chamber, Austria. This measure is very important, as it will bring Austria into direct communication with the port of Salonica Herr von Schmerling remarked that he looked upon the Austrian occupation of Bosnia not as a temporary but as a permanent thing. This railway, he thought, would help to attach the natives of the province to Austrian rule by identifying their interests with those of the empire.

RAILWAYS AND CANALS IN CANADA.—The report of the Minister of Railways and Canals of Canada for the year ending June 30, 1880, has been presented to the Dominion Parliament. It is stated that on the section of the Canadian Pacific Railway from Thunder Bay to Rat Portage, 294 miles, the railways for 171 miles are laid, and from Kiewatin (Rat Portage) to Selkirk on the Red River, 112 miles, the railways are down the whole way. For a distance of 16 miles beyond Red River, up to Victoria junction, Selkirk, no line has been constructed, but communication is open to Winnipeg by means of the Pembina branch on the east side of the river, and a temporary bridge over the river connects the line with the Winnipeg branch. Westwards the railways are laid to within a few miles of the western boundary of Manitoba, and the line is in operation to Portage-la-Prarie, 70 miles west of Winnipeg. The Canadian Pacific Railway therefore has at the present time 232 miles in work as follows: Emerson to Winnipeg, 63 miles; St. Boniface to Selkirk, 23 miles; Selkirk to Cross Lake (east), 76 miles; Selkirk to Portage-la-Prarie, 70 miles. In British Columbia 127 miles are under contract, and are being steadily prosecuted. The expenditure in connection with the Pacific Railway during the last fiscal year was $4,444,572. The enlargement of the canal system is being rapidly proceeded with, and during last year the expenditure on that account was $2,125,455. The new canals when complete will have a uniform system of locks, 270 feet long by 45 feet wide, with a depth of 14 feet, and will enable steamers of 1500 tons to pass from Lake Superior to Montreal and the sea. The total length of inland navigation from Lake Superior to the Straits of Belle Isle is 2384 miles, and the completion of the new work cannot fail, it is considered, to have an important effect upon the transport of grain from the Western States of America and Western Canada to the United Kingdom.

FRENCH RAILWAYS.—The Director-General of Railways in France has recently published the results of working the main French lines during the first nine months of 1879 and 1880, which returns show a marked improvement between January and September, 1880. The total gross receipts during these nine months amounted to £30,292,000, or nearly 3½ millions more than during the corresponding period of 1879. During the year ending September last, 591 miles of new lines had been opened for traffic. The gross receipts of £30,292,000 were divided among the old and new *reseaux*, the railways belonging to the State and those of private companies as follows: The old *reseau*, 6244 miles in length, earned £22,847,000, or more than 70 per cent. of the total. The new *reseau* of 6253 miles earned £6,798,000. The State railways, 1179 miles long, earned £537,600, and the various private lines, 517 miles in length, have earned the remainder of the total. These results show a large increase over the corresponding period of 1879; thus the old *reseau* shows an increase of £2,486,000; the new *reseau* a rise of £791,000, and the State Railways a rise of nearly £50,000. The line from Rhone and Mont Cenis Railway classified in the Paris, Lyons, and Mediterranean system, earned £167,360 during the first nine months of 1880, or nearly £18,000 more than in the similar period of 1879; the former figure represents an earning of over £2300 per mile of line.

ORDNANCE AND NAVAL.

AN HYDRAULIC SHIP.—Another hydraulic ship has lately been launched in Germany, but as usual with vessels of the same description, she has failed to attain the speed expected. As the readers of *Iron* are aware, in these hydraulic ships water taken in through the bottom is expelled at both sides in the line of the keel, and the reaction of the fluid issuing at high speed drives the hull ahead if the water is allowed to escape aft, or astern if it escapes towards the bow. The notion is no new one, for as far back as 1661 an inventor received a patent for propelling vessels by expelling water from their sterns. In 1730 another patent was secured for doing nearly the same thing, and since that time nearly fifty persons have taken out patents for hydraulic vessels. About ten years ago a vessel called the "Waterwitch," of 1279 tons displacement, was built for our navy, to test a proposed system of hydraulic propulsion, but, though the ship is only of light draught, has good lines, and is fitted with engines of 775 horse power, she has never exceeded, when at sea, a speed of from five to six knots, and has never been trusted out of sight of land. The hydraulic ship lately built in Germany is 110 feet long, 17 feet wide, with a draught of 15⅛ feet of water, and was expected to attain a speed of ten knots an hour, but on her trial trip she could barely accomplish nine. She proved, however, to be extremely handy, running close up to a sailing vessel which crossed her course, and then, stopping her way in a moment, turned immediately to starboard.

THE AUSTRIAN IRONCLAD "TEGETHOFF."—A trial of a new steam fire engine, designed for the Imperial Austro-Hungarian warship Tegethoff took place on Tuesday at Messrs. Merryweather and Sons' fire-engine works at Greenwich. The engine is fitted with a quick-raising steam boiler of the Merryweather and Field improved type. The pump is provided with valves having large clear openings through which seaweed, shavings,

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straw, and other foreign matter may pass without fear of injury or stoppage to the machinery. At the trial steam was raised within eight minutes from cold water, and the engine pumped 360 gallons per minute through a 1¼-inch jet to a height of 160 feet. Following this test two, three, and four jets were thrown by the engine simultaneously, and as an experiment, to show its capabilities for pumping powers the machine discharged an immense body of water through two 2½-inch hoses. This last experiment was perhaps the most important to the visitors present, as the primary work of the engine (although a fire engine to all intents and purposes) is to pump out water in case of a mishap, damage by torpedo or shot. Being complete in itself, such an engine by means of suction pipes can draw water from any damaged compartment, and keep it down until the necessary repairs are made.

THE NEW FORTY-THREE TON BREECH-LOADING GUN.—The heavy breech-loading gun now in course of its departmental trials in the Royal Gun Factories naturally excites much interest, being the first breech loader in our service larger than the old Armstrong 7-inch guns, which fired shot weighing 110 pounds, with considerable difficulty, and were eventually supplied with shells under 100 pounds in weight. The new gun weighs about 43 tons. Its caliber is 12 inches, and its length of bore about 26 calibers—the whole gun being about 29 feet long. The method of closing the breech is the same as that adopted in the new field breech-loading guns, except that lever and screw power is applied to the closing and locking of the breech. In general appearance, proportions, and character, the gun closely resembles the 9.2-inch breech-loading Woolwich gun depicted in *The Engineer* of June 25, 1880. The new armor-clad vessels Colossus and Majestic will each, we believe, carry four of this description of gun, mounted in two turrets, arranged similarly to those of the Inflexible, which vessel they will closely resemble. They are to be 5 feet longer and 7 feet narrower, and are to be made of steel, with compound armor 16 inches thick. For a full description the reader is referred to King's "War Ships," new edition. Up to the present time the gun in question has not been the subject of any public trial, being, as we have said, in the course of undergoing its early proofs in the hands of Colonel Maitland, the Superintendent of the Gun Factories. In this stage it is impossible to give full detailed information. We think, however, that we can supply what is sufficiently near for all practical purposes. The gun was fired on Thursday, January 6th, with about 280 pounds of prismatic powder, which, with a projectile weighing 703 pounds, gave an initial velocity of about 1830 feet per second. The charge is being gradually increased—the pressure in the bore being as yet only about 16 tons on the square inch. Taking it in its present condition, however, the gun is a very powerful weapon, having about 16,330 foot-tons stored-up work, or 435 foot-tons per inch circumference, which means a penetration of from 22 inches to 23 inches—on the service system of calculation, nearly 25 inches. This is the class of gun we have before commended as likely to be useful in future times. It is capable of piercing wrought iron of the thickness of the armor employed on the Duilio. As a matter of fact, the plates of that ship are steel, so that they could not be penetrated, but must be destroyed by racking. For its size, the racking power of the 43-ton gun is very great. The 35 ton was of the same caliber, it had 8203 foot-tons stored-up work, a penetrating figure of 219-06 foot-tons, and about 16-inch penetration. Thus, for 8 tons increased weight the new gun nearly doubles the quantity of stored-up work and the penetrating figure. We must not blink the fact that 29 feet is a length of gun involving special allowance in the turret and deck. The maximum width of both the Colossus and Majestic is 68 feet. The power of this piece then is very great, and we have not yet reached the maximum development. On the most recent trials a velocity of 1930 feet was obtained with 300 pounds of powder, and a pressure of 19 tons on the square inch.—*Engineer.*

BOOK NOTICES.

PUBLICATIONS RECEIVED.

ILLUSTRATED CATALOGUE OF THE BALDWIN LOCOMOTIVE WORKS.

OFFICIAL GAZETTE OF THE UNITED STATES PATENT OFFICE. Vol. 19, No. 7.

TWELFTH ANNUAL REPORT OF THE BOARD OF RAILROAD COMMISSIONERS OF MASSACHUSETTS.

MONTHLY WEATHER REVIEW FOR JANUARY, 1881.

THE WORKSHOP. No. 3. E. Steiger & Co.

THROUGH the kindness of Mr. James Forrest, Secretary of the Institution of Civil Engineers, we have received the following published papers of the Institution.

"Address of James Abernethy, Esq., F. R. S. E."

"Machinery for Steel Making," by Benj. Walker, M. I. C. E.

"The Monte Penna Wire Ropeway," by William P. Churchward, A. I. C. E.

"Cribwork in Canada," by Henry Taylor Bovey, M. A.

"Different Modes of Erecting Iron Bridges," by Theophilus Seyrig, M. I. C. E. Translated by Alfred Bache, A. I. C. E.

LOCOMOTIVE ENGINEERING AND THE MECHANISM OF RAILWAYS. By Zerah Colburn. For sale by D. Van Nostrand. Price $10.

This is not a new book, nor is it a new edition of an old one, but attention is called anew to this valuable treatise by the announcement of a material reduction in the price. Two large quartos, describing and illustrating in

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the fullest manner every department of locomotive structure and use, are now offered for ten dollars.

The plates afford working dimensions, and the text fully describes the details.

CAOUTCHOUC; GUTTA PERCHA ET GOMME FACTICE. Paris: Librarie de Roret. For sale by D. Van Nostrand. Price $1.75.

There are two volumes of this little French work, of which the first is devoted to caoutchouc. The methods employed in preparing the raw material, and the machinery for the manufacturing processes are briefly described. The plates are good, although few in number.

NOUVEAU TRAITE DE CHIMIE INDUSTRIELLE. Wagner et L Gautier. Paris: Librairie F. Savy. For sale by D. Van Nostrand. Price $10.50.

This extensive work is now in two large octavo volumes illustrated with the best style of woodcuts and in the most profuse manner, there being 487 such illustrations in the work.

The first section of the work treats of Metallurgical Processes; the second, of Raw Materials and Products of Industrial Chemistry; the third, of Glass, Pottery, Lime and Plaster; fourth, Vegetable Matters and their Industrial Applications; fifth, of Animal Matter; sixth, Coloring Matters; seventh, Illumination; eighth, Heating, the Materials and Apparatus.

LIFE HISTORY OF OUR PLANET. By Wm. D. Gunning. New York: R. Worthington. Price $1.50.

This is paleontology in a popular, not to say an unscientific form. Facts are gleaned here and there from the zoology of the past, and presented in the style of the popular scientific lecturer.

There is a tendency in all such works to give undue prominence to the astounding facts, and to omit the expression of their logical connection; but it may be urged that by such means the attention of the unlearned is first arrested and directed to the proper sources of information.

The book is fairly illustrated, and will, we have no doubt, be gladly received in those sections of the country where the author has been heard on the lecture platform.

EASY LESSONS IN SANITARY SCIENCE. By Joseph Wilson, M. D. Philadelphia: Presley Blakiston. Price $1.00.

Land Drainage, Drainage of the Farm House and Village, Drainage of Cities, and Plumbing, are the topics treated in an easy colloquial style by this author.

The writer possesses sufficient knowledge, derived from experience, and has produced a valuable, though brief and badly illustrated treatise.

MATERIALS AND CONSTRUCTION. By Francis Campin, C. E. London: Crosby Lockwood Co. For sale by D. Van Nostrand, Price $1.20.

This is a new volume of the well-known Weale series. It is prepared by a well-known author for those readers who desire to become thoroughly acquainted with theories of structures, and the practical application of results in the simplest way, and not as a mathematical exercise.

A convenient and compact volume is the result of this plan, containing as much science as a large proportion of working engineers are accustomed to employ.

THE STEAM ENGINE AND ITS INVENTORS. By Robert L. Galloway. London: Macmillan & Co. Price $3.50.

This is a brief history of the use of steam from 1660 to 1820. The object of the author, as explained in the preface, is to exhibit the successive steps in the development of the cylinder and piston engine, and not to give an account of all the machines in which steam has been employed.

The book is well printed, and the illustrations are excellent, although the latter will look familiar to readers of former sketches on this subject, and the number will seem small compared with the abundance afforded in Thurston's history of the steam engine.

The bibliography of the subject seems to be fully given in the foot notes, a fact that will render the work valuable to students or writers upon subjects relating to the history of engineering progress.

THE MARINE MAMMALS OF THE N. W. COAST OF NORTH AMERICA. By Charles M. Scammon. New York: G. P. Putnam's Sons. Price $10.00.

This is an illustrated quarto, giving, in addition to the habits of the whales, seals and Dolphins, an account of the methods of the American whale fishery.

The book will prove valuable to the naturalist seeking for full information on these subjects, and will also prove acceptable to any lover of natural history by reason of the fullness of the descriptive text and illustrations.

SEWING MACHINERY. By J. W. Urquhart, C. E. London; Crosby Lockwood & Co. For sale by D. Van Nostrand. Price 80 cents.

This is a late addition to the Weale series, devoted exclusively to an historical and descriptive account of the sewing machine. It will doubtless prove interesting to many, and valuable to a few who need in one book the information heretofore scattered through the technical journals of several years.

MISCELLANEOUS.

WATERPROOF paper is made by a new German method as follows: To a weak solution of ordinary glue add a little acetic acid; then make another solution by dissolving a small quantity of bicromate of potash in distilled water. These two liquids should be we

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mixed together, and the sheets of paper which have to be made waterproof drawn through the mixture, and suspended from suitable lines to dry. The proportions are not given, but 5 per cent of acetic acid and 7 per cent. of a saturated solution of bicromate of potash will answer.

THE manufacture of bicycles and velocipedes has become one of the staple industries of the Midlands, and lately the railway charges for the carriage of these products have been considerably increased, in some cases up to 100 per cent. The manufacturers of Wolverhampton and Coventry have consequently interviewed the managers of the London and North-Western, the Great Western, and the Midland Railways, seeking a return to the rates that prevailed before 1881. The result has been that with this month the recently advanced rates have been lowered 50 per cent. on bicycles, and something like 75 per cent. on tricycles. The manufacturers in the Wolverhampton district have formed themselves into an association.

DIURNAL VARIATIONS OF THE BAROMETER.—G. H. Simonds has computed the barometric coefficients of daily variations from observations made at thirty stations scattered over the globe. The average duration at each station was something over ten years. Under the tropics the effect of latitude is scarcely perceptible, but between the latitudes of 20° and 60° the value of the quadrantal component decreases .001 inch per degree of latitude. The calculations and the discussions which have resulted from them confirm Sir John Herschel's views, in regard to the universality of the phenomenon, and Chase's explanation of the cause.

CIRCULATION OF AIR IN THE ST. GOTTHARD TUNNEL.—M. Stapf has been giving careful attention to the variations in the air currents between the two openings at Göschenen and Airolo. He finds two principal causes to be operative in these changes: First, the southern opening is 30 meters (32.809 yards) higher than the northern, which represents a pressure equivalent to that of a column of air 36 meters (39.371 yards) high at the subterranean temperature; second, the difference of barometric pressures upon the two declivities of the mountain. If the external temperature was always lower than the internal, if the barometric temperature was the same at each side, and if there were no modifications of velocity due to the heating and expansion of the air or to the friction against the walls, the draft would always be southward. Meteorological observations are regularly taken, both at Airolo and Göschenen, to determine the elements which are required in order to know, monthly or annually, the number of days for which a given direction of current or an absolute calm may be expected in the interior of the tunnel.

THE new law upon trade marks now in force in Switzerland embraces three points of procedure, viz.: deposit, registry, and renewal. The act of deposit—made at the Federal Bureau at Berne—must be accompanied by a legal attestation as to the place of manufacture; the trade mark in triplicate, with exact description of the article; a block of the trade mark, of a specified size and thickness; and lastly, a sum of 20f. for each separate trade mark. The deposit can be made by a third party by procuration. The registration must contain information as to the number of the trade mark; the data of deposit and publication; the name, profession, and address of the proprietor; the description of the article and of any modifications which might have been made since the day of deposit. The description is given in the language of the depositor, provided it is in one of the three national languages; if otherwise, in French. Renewal is accompanied by the same formalities as deposit. The law on trade marks does not deal with, or affect in any way, the law of patents, which which will form a subject of debate in the renewal of commercial treaties between Switzerland and the neighboring States. *Apropos* of this, says a contemporary, it may be mentioned that an international conference upon the law of patents has just been sitting in Paris, in which M. Kern, the Swiss Minister to France, has taken part.

COLOR RELATIONS OF METALS.—In a paper on the color relations of copper, nickel, cobalt, iron, manganese, and chromium, lately read before the Chemical Society, Mr. T. Bayley records some remarkable relations between solutions of these metals. It appears that iron, cobalt, and copper form a natural color group, for if solutions of their sulphates are mixed together in the proportions of 20 parts of copper, 7 of iron, and 6 of cobalt, the resulting liquid is free from color, but is grey and partially opaque. It follows from this that a mixture of any two of these elements is complementary to the third, if the above portions are maintained. Thus a solution of cobalt (pink) is complementary to a mixture of iron and copper (bluish green); a solution of iron (yellow) to a mixture of copper and cobalt (violet); and a solution of copper (blue) to a mixture of iron and cobalt (red). But, as Mr. Bayley shows, a solution of copper is exactly complementary to the red reflection from copper, and a polished plate of this metal viewed through a solution of copper salt of a certain thickness is silver white. As a further consequence, it follows that a mixture of iron (7 parts) and cobalt (6 parts) is identical in color with a plate of copper. The resemblance is so striking that a silver or platinum vessel covered to the proper depth with such a solution is indistinguishable from copper.

There is a curious fact regarding nickel also worthy of attention. This metal forms solutions, which can be exactly simulated by a mixture of iron and copper solutions; but this mixture contains more iron than that which is complementary to cobalt. Nickel solutions are almost complementary to cobalt solutions, but they transmit an excess of yellow light. Now the atomic weight of nickel is very nearly the mean of the atomic weight of

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iron and copper, but it is a little lower, that is, nearer to iron. There is thus a perfect analogy between the atomic weights and the color properties in this case. This analogy is even more general, for Mr. Bayley states that in the case of iron, cobalt, and copper, the mean wave length of the light absorbed is proportional to the atomic weight. The specific chromatic power of the metals varies, being least for copper. The specific chromatic power increases with the affinity of the metal for oxygen. Chromium forms three kinds of salts. Pink salts, identical in color with the cobalt salts; blue salts, identical in color with copper salts; and green salts, complementary to the red salts.

Manganese, in like manner, forms more than one kind of salt. The red salts of manganese are identical in color with the cobalt salts, and with the red chromium salts. The salts of chromium and manganese, according to the author, are with difficulty attainable in a state of chromatic purity. He thinks these properties of the metals lead up to some very interesting considerations,

JAPANESE LEATHER PAPER.—Among the numerous forms in which Japanese art has been so popularly represented in this country of late years there are few proving so practically useful as the subject of this notice. Introduced at a time when startling innovations were being made in matters of taste, it readily lent itself to the efforts of designers who were gifted with fresh and original ideas. With no associations wedding it to any particular style, and with a character which neither asserts nor obtrudes itself, it harmonizes with almost every style of decoration. The paper is rich and generous in color and charming in design. Some have wonderful bits of detail, amidst a mass of suggested form and foliage; others show more than a suspicion of European influence. One of the latest now before us has all the familiar features of the best old Spanish leather, but accentuated in a manner both novel and characteristic. But whether drawn from their own resources or elaborated on accepted forms, they are peculiarly adapted for the purposes for which we recommend them, viz., interior decoration, such as dados, entrance-halls, staircases, &c. But from their variety, both in design and color, they can also be used with fine effect wherever decoration is introduced. Apart from its value as a decorative agent, Japanese leather paper possesses in a large degree the desirable quality of durability, and in this respect thoroughly deserves it name, being practically indestructible when once fixed on a wall. The origin of this interesting material in its present form may be regarded as a legitimate outcome of one of our International Exhibitions. Before 1872 specimens of the material were only to be found in the hands of dealers or collectors. But in 1872 two or three pieces of the then orthodox size, that is, 18 inches by 12 inches, in no way striking in pattern, were exhibited in a case at South Kensington, where they were regarded only as an object of curiosity. Mr. Robert Christie, recognizing its value as a material for the purposes for which it is now so largely used, and having at that time business connections with Japan, at once endeavored to find out the makers there, with the view of getting it produced in a form more useful for European requirements. His efforts were so far successful that he was enabled to exhibit several rolls of different patterns, measuring 3 feet wide by 36 feet long at the Exhibition in 1874, and for which he obtained a medal. Since then Mr. Christie has been in constant correspondence with the makers in Japan, and, having had practically the monopoly of its manufacture up to the present time, has used his influence in impressing on them the desirability of adhering as near as possible to their own old colors and designs. Although the manufacture of this material has been largely developed, its reproduction has in no manner deteriorated, unlike other native productions both of India and Japan, where trade competition and indiscriminate orders have had such a baneful influence on their art work; the only deviation from this rule being as regards size, in order to do away with the patchy and unsatisfactory appearance which was found to be unavoidable where the original small pieces were used, particularly in cases where the pattern ought to, but did not intersect. We are glad to hear from Mr. Christie that its sale at the present time is largely increased both in this country and America, and it is now regarded by an intell gent class of decorators as one of the mos promising staples of trade with Japan.

THE Phosphor-Bronze Company held its seventh annual general meeting on the 1st inst. The directors declared a dividend of 10 per cent. per annum, less the interim dividend—2½ per cent.—already paid. The directors have devoted, they say, considerable attention to several novel applications of phosphor-bronze—amongst others, to its adaptability in the form of sheet, angle bars, and rivets, to the construction of steam launches and torpedo boats; and having thought it desirable to make a practicable trial in this direction, they have ordered a small steam launch to be built entirely of phosphor-bronze, to test its greater durability by reason of its resistance to the oxidizing effect of sea water. Should the venture prove a success, there is every likelihood of a considerable business developing in this branch.

THE agreement amongst the coalowners of Germany has been revived. Where the limit of 45,000 tons in the output has not been exceeded, the same production is allowed for 1881. New members of the ring must undertake to reduce their output by 5 per cent., and to agree to a fine of 1f. 25c. for every ton above 45,000. The fine is, however, in no case to exceed 125,000f.

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THE AUTHOR.

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VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CXLIX.—MAY, 1881.—VOL. XXIV.

SMALL MOTIVE POWER.

By HENRY S. H. SHAW, Stud. Inst. C.E.

From Selected Papers of the Institution of Civil Engineers.

II.

AIR.

After some long and thorough trials on a large scale of hot-air engines, the most important of which were at the Dundee Foundry, about 1845,* and on the ship Ericsson, 1852, hot air has been universally acknowledged to be adapted only to perform operations requiring but little power, its present application in this country being almost entirely confined to the immediate supersession of hand labor. The hot-air engine has, however, a high efficiency, and in the first of the above cases, Mr. J. Stirling, the son of the original inventor, stated that the Stirling engine, then described, used only 2½ pounds of coal per hour per HP., which was said to be ⅓ of that used by the best steam engines of the day; and in the discussion which followed, the author stated that he had "every reasonable confidence in its ultimate success." Again, in the second case in which Ericsson's engine was used, the action of which is described by Professor Rankine,† the consumption of anthracite was 1.87 pound per hour per HP., where, "notwithstanding the low efficiency of the furnace, ... the efficiency of the fluid was so great as to give a resultant efficiency superior to that of almost all steam engines at the time of the experiments referred to." In spite of these facts, it was not till a few years ago that small hot-air engines had any considerable use in this country. The reason for this has been already referred to—the high temperatures required, and the narrow range of effective pressure; the latter rendering bulky apparatus necessary to produce much power, the former rendering the mechanical difficulties in dealing with that apparatus very great, as, for instance, the permeation of the glowing fire box by the air under compression, which it has been proved takes place. Now, however, there are several successful patents for hot-air engines whose great recommendation is the absolute freedom from danger of explosion, and almost noiseless action, together with a high efficiency. There are two kinds of engines which, according to the method of using the working fluid, are called "closed" or "open." The two engines above mentioned are prototypes of these two classes. In the Stirling engine the same mass of air under pressure was used continuously, and by alternate heating and cooling was made to do work; it is therefore called "closed." In the Ericsson engine

* *Vide* Minutes of Proceedings Inst. C. E., vol. iv., page 348.

† "A manual of the Steam Engine and other Prime Movers," 8th ed., p. 361.

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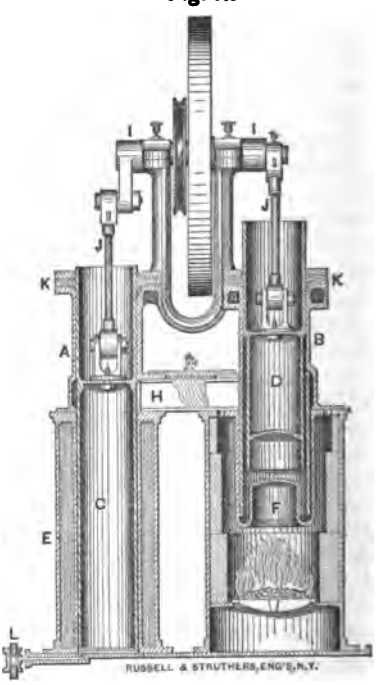
a fresh supply of air was taken in by the engine at every stroke, in a similar way to steam from a boiler, and after doing work by the application of heat, was rejected in a similar way to steam; it is therefore called "open." With regard to the latter, little will be said; for as far as the author is able to learn, they are scarcely if at all used in this country. In Germany the open engine of Hock, and in France that of Belou, give satisfactory results, but these differ in an important point from the Ericsson engine, the air not being heated by mere contact with a metallic surface, but being made to pass through the fire and support combustion, thus bearing a resemblance to the action of gas engines. In a trial of the Belou engine at Cusset, quoted by Mr. D. K. Clark (p. 918, "Rules and Tables"), the consumption of coal was 0.735 pounds per hour per I.HP., and 3.24 pounds per net HP. at the brake. In a trial of a Hock engine by Professor Jenny, of the Imperial Technological School of Vienna,* 7 kilogrammes of coke were used in sixty-three minutes by an engine developing 1.58 HP. at the brake, which is almost exactly equivalent to 9¼ pounds of coke per hour per HP. These results compare favorably with the work done by most closed air engines, but the Belou engine was of large size—of more than 27 HP.; and it is the Hock engine, or one similar to it, which is of low first cost, and has many advantages, that must be regarded as the one whose introduction might profitably take place, and which is spoken very highly of in the report referred to.

Closed air engines are numerous; those of Laubereau, Lehmann, Stenberg (the Calorisca), D. van Rennes, and Rider being the principal. With each there is some difference in theory, as shown by Dr. A. Slaby.† A distinction can, however, be made between single and double-acting engines. Laubereau's, which is a modification of Stirling's, is commonly used in France; while in Germany Lehmann's is most popular, as testified by the fact that over a thousand are there in use. Both Lehmann's and Stenberg's have a brickwork erection at the end distant from the crank shaft, and, being horizontal, considerable space is necessary. While the machinery of Lehmann's is decidedly complicated, Laubereau's is vertical, and very compact and portable, and, in spite of the alleged defect pointed out by Dr. Slaby, which is avoided in Lehmann's engine, viz., that the heating chamber communicates directly with the working piston, and so renders the packing liable to rapid deterioration, it has worked satisfactorily, using, in a trial quoted by Mr. D. K. Clark, 4.8 pounds of coal per hour per HP., and 11 pounds per HP. at the brake. Lehmann's engine has been recently introduced into this country, and was awarded the first prize at the Manchester and Liverpool Show, 1879; but at present the engine most generally

Fig. 11.



used is that of Rider, of which, since its introduction from America three years ago, upwards of nine hundred have been sold; therefore, of this only will a description be given. Fig. 11 is a sectional view taken from the prospectus of the company; it is there seen to be single-acting, and to consist of two cylinders, A and B, in which two vertical hollow

* Klein-Kraft-Maschinen," p. 42.
† *Vide* Minutes of Proceedings Inst. C. E., vol., p. 870.

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plungers, C and D, work air-tight for a portion of their length, driving cranks set at 95° on the shaft above. The method of packing is most ingenious, consisting of two reversed leather collars, which seem to wear satisfactorily, although in direct communication with the heating chamber. A is the cooling or compression cylinder, in which, by the device of an annulus of air between the plunger and casing E, round which water circulates, a rapid cooling can be effected; and in the same way an annulus of air in the other, or working cylinder B, enables a rapid transfer of heat to take place when this is necessary. The action is as follows: When the air in C is compressed by hand at starting to about ⅓ its original volume, the rising of the piston B, which is of equal area, enables it to be transferred without change of volume to that cylinder with which there is a communication. Here the heating, which is facilitated by the shape of the bottom of the plunger, takes place, and the consequent expansion causes the continuance of the upstroke of D. Upon the return stroke of D, the air is transferred to the compression cylinder, but is made on the way to give up heat to the thin plates in the regenerator H, of which a partial view is shown, and this heat is restored when the repetition of the first operation takes place; the rest of the heat which must be abstracted is taken away by the water in the casing, and the engine now continues to work, the difference between the positive work in the working cylinder, and the negative work in the compression cylinder being the effective work. The ½-HP. engine has been found to consume 4 pounds of coke per hour; the 1-HP. a little more than twice that amount. One was tested at the Royal Agricultural Show at Birmingham, and the work done by pumping showed a consumption of 13 pounds of coal per hour per HP., or a little more than ¼ that used by the pulsometer pump, or ⅓ of that in the Tangye pump, in the experiments already referred to. The cost of coal for a week's work of six days, working ten hours a day, is advertised not to exceed 2*s.* 6*d.* for a ½-HP. engine. These engines are thus economical; they are reliable and simple in action, and require no skilled attendant; they are safe, and, in pumping operations, for which they are usually applied, the water pumped can be made to circulate in the casing, and so act as a cooler; but, in common with nearly all hot-air engines, they are heavy in proportion to their power. Hot-air engines, then, have decided advantages, and in the country their employment might, and probably will be, profitably extended.

Compressed air has been applied to transmit power for a variety of objects; but the purpose for which, on a small scale, it seems specially adapted, is to supersede manual and animal labor in rock boring and mining operations. For mine and tunnels there are many advantages attending its use; for not only is the air which is compressed by external machinery of great importance for ventilation, but the fall in temperature by expansion, which accompanies the necessary loss of heat occasioned by its use, is valuable, as tending to reduce the temperature in close and heated workings. The principal objects to which it is put are for underground haulage, pumping, and rock boring or coal-cutting operations. The first of these has been considered by Mr. W. Daniel, in a paper before the Institution of Mechanical Engineers,* and is rather applied to motors of a size not here dealt with; the second may use any of the ordinary steam pumps; but it is the last which is particularly an example of the successful application of machinery to replace individual physical effort. A vast amount of attention and ingenuity have been bestowed upon rock-boring and coal-cutting apparatus, of which drilling shot holes in the former is the most important and toilsome part of the labor required, and one to which the application of motive power has been most beneficial. Only one form of rock borer will be described, but one which, at the Bristol docks, has proved efficient and durable. Figs. 12 and 13 are two views of the drill of R. Schram; the action simply imitates that of hand boring, viz., a succession of blows, accompanied by a turning motion. The machine consists of a strong cylinder supported by three legs, in which works a solid piston rod, driven by a double piston, the end of the rod carrying the

* *Vide* Institution of Mechanical Engineers. Proceedings, 1874, p. 204.

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drill. The blows are given as rapidly as 400 or 500 per minute, by means of the valve *f f*, which acts in a somewhat similar way to that of the special pump; when the opening *o*, shown by dotted lines, in the cylinder is open to the pressure of the air, the opposite end of the valve will be also under pressure, and will remain in one position; but directly it is opened to the exhaust, by the edge of the piston passing it, the end of the valve will also be opened to the exhaust, the pressure removed, and the valve thrown over, and the action on the piston reversed.

Fig. 12.

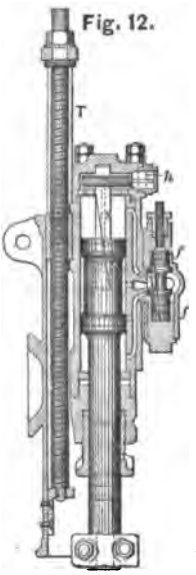
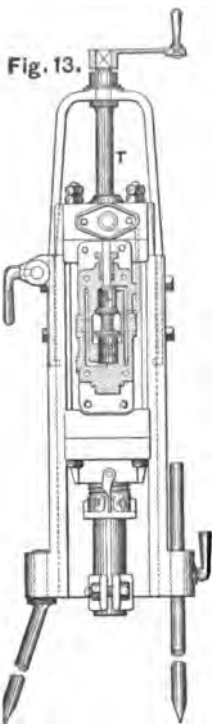


Fig. 13.



Similarly for the opening *o'*, communicating with the other end of the valve. The second action, or turning, is effected by means of a small piston *p*, shown in section, Fig. 13, which acts at right angles to the stroke of the drill, but is not quite in the same center line, and therefore every stroke it takes will turn the ratchet wheel *w*, which is in that line, and, consequently, the position of a spiral rod *s* fitting into the end of the piston rod. This happens when the drill is down, and the spiral rod free from it; but when the drill and piston rod make the in-stroke, the spiral rod running into the former, and being itself held firmly, turns it through the necessary angle; in the out-stroke no turning takes place. The feeding is effected by the hand-screw T.

It is well known that compressed air necessarily involves considerable loss, from the fact that most of the heat developed by compression cannot at present be retained, so as to act when the converse expansion takes place in the motor. This subject has been fully treated, both theoretically and experimentally, by many engineers, especially in France. From Mr. Robinson's paper,* already referred to, the total loss appears to be never in practice less than 50 per cent. of the energy used in compression, and sometimes as much as 75 per cent. Again, the result of some experiments by Mr. W. Daniel shows a loss† from 54.2 per cent., with 19 pounds per square inch air pressure, to 74.2 with 40 pounds air pressure.

But the work lost is more than compensated for by the attendant advantages, and where, as in the Mont Cenis tunnel, a natural head of water can be employed, it must be superior to all other agents; though for purposes above ground, notwithstanding several attempts to introduce it, and except in the Westinghouse brake, the loss with compressed air is sufficient to prevent its general adoption, and even rock-boring drills are then worked by steam.

WATER.

A natural head of water was, perhaps, the first power applied to take the place of manual labor, and though used all over the world on a large scale, and in Switzerland and some other countries for small powers—where mountain streams are employed even for such domestic purposes as churning and rocking cradles—yet in this country the extension of small water motors has been confined almost entirely to towns having artificial sources of supply. Nevertheless, as has been forcibly brought forward on several occasions of late, the natural power at

* *Vide* Minutes of Proceedings Inst. C. E., vol. xlix., p. 17 *et seq.*

† *Vide* Institution of Mechanical Engineers. Proceedings, 1874, p. 210.

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present running to waste might, by means of more efficient transmitting agencies, be taken advantage of. There are several instances in which this is being done, as at Tortona, in Italy, where, since 1876, the force of the torrent Scrivia has been made to supersede steam by applying telodynamic transmission, and a daily saving of 60 per cent. in cost thereby effected.* Again, on the estates of M. Menier, the power derived from the river Marne is used, by means of electric transmission, for ploughing and other agricultural purposes, and it is proposed to extend it to a distance of 3 miles from the source. Also, in America the use of the almost boundless supply of natural head of water is being rapidly extended for similar labor-saving objects; but it is a significant fact with regard to this country, that although Sir W. Armstrong, who, if not the first, has certainly been the chief, engineer in introducing the present hydraulic system, was led to the subject by noticing the waste above referred to. His first idea, like that of many others, was to prevent that waste, and he has established a magnificent system, not, however, based upon the use of the natural source of power, but upon a source whose essential principle is the production of an artificial head of water—in most cases by the use of steam. The fact is, that the supply of power referred to must be turned into work at its source, or stored up under a, so to speak, higher pressure; since, when it is the power of the water, and not the water itself that is required, the proportional loss by transmission would otherwise render its use impracticable. Now the obvious advantages to small industries from localization seems to account for the undoubted tendency in this country to cary on small manufactories in towns, to which the power must be conveyed: therefore, their connection with the natural source is an important problem, the solution of which necessitates (1) an abundant supply, and (2) an efficient means of transmission. England cannot be said to be rich in the former, and the latter is far from being in a satisfactory or settled state; so that, until the want of fuel is more keenly felt, artificial sources will in towns, no doubt, continue to be principally used. Still in the country small water wheels, or turbines, are often conveniently applied, and many of the former have been erected by Mr. W. Anderson, M. Inst. C. E. (of the firm of Messrs. Easton and Anderson), of 0.018, 0.04, 0.26, &c., H.P., chiefly for pumping purposes.*

The two sources of water power in a town are:

(1) The reservoirs for supplying water for domestic purposes.

(2) The accumulators specially erected for obtaining a head of water.

Up to the year 1849 the supply in towns was drawn from reservoirs, and it was one of the original ideas, set forth in a letter by Sir W. Armstrong, F.R.S., V.-P. Inst. C.E., to the Mechanics' Magazine," and referred to by him in a paper before the Institution,† that "the water already supplied to towns for domestic purposes could in many cases be advantageously employed for working cranes, printing presses, and in short, all kinds of machines where manual labor was usually employed." This is an artificial source, since steam engines are generally employed to raise the water into the reservoirs. The expense, however, is a serious consideration, for it must be remembered that the water is supplied for a different purpose, and the head is only made sufficiently great to distribute the water to the summit of the various buildings, and in London, for instance, it is not even so great as that. Besides being small, the pressure is found to vary considerably, and not only by diurnal changes, due to reasonable causes—it being, for example, 45 pounds per square inch at Westminster in the morning, and rising to somewhat over 60 pounds in the afternoon, and in Bristol from 40 pounds to 70 pounds—but also to sudden and erratic changes, most trying to the water motor employed. The consumer is, nevertheless, charged for the quantity used, independently of the pressure; and as inquiry seems to indicate that this is often highest in the towns where the average pressure is lowest, the system must be far from satisfactory. These causes no doubt led to

* *Vide* Minutes of Proceedings Inst. C. E., vol. 1., p. 192.

* *Vide* Transactions Inst. C. E. of Ireland, vol. ix., p. 78.

† *Vide* Minutes of Proceedings Inst. C.E., vol. 1., p. 66.

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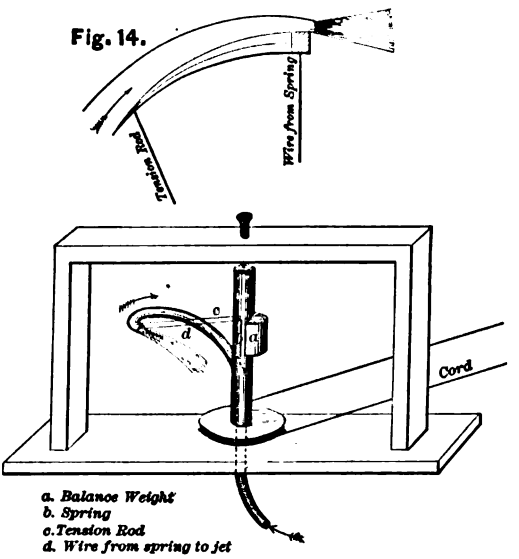
the second method, viz., the use of the accumulator for supplying water under considerable pressure, which brought out the advantages of water as an agent, and showed its superiority under great pressures, from its incompressible nature, which both renders it capable of transmitting great power and at the same time obviates all danger from explosion; and the size of the motor can be so reduced as to render the amount of water used but trifling. The pressure under which the water is used has everything to do with the kind of motor employed; and before comparing the



cost of the two foregoing modes of supply, the types of apparatus must be discussed.

No doubt the motors giving the highest efficiency, under proper conditions, are turbines and reaction wheels, but these conditions are such as to exclude them for water under much pressure, and even with water from the mains the use of the former is practically out of the question, for the linear velocity of the rim of the wheel should bear some ratio to the velocity due to that pressure, and as the size of the wheel diminishes, its number of revolutions must, for a constant head of water, increase; so that to obtain any reasonable efficiency, the velocity for a very small wheel would have to be as much as 4,000 or 5,000 revolutions per minute. The inward-flow turbine of Professor James Thomson is made to very small sizes; but in a letter to the author the inventor says: "I do not recommend any kind of turbines for ordinary use with very small water supplies and high-water pressures." The reaction wheel can be made to work economically up to moderately high pressures, because the radius of its discharge orifices can be increased, and so the law connecting the head with the linear velocity of the jet (which is velocity $=8\sqrt{h}$) can be nearly satisfied. In a paper read by Mr. W. C. Kernot, M. A., C. E.,* at Melbourne, a small motor of this kind, shown in Fig. 14, is advocated, in which, by means of a counterweight a, one arm is dispensed with, and the hydraulic radius doubled, all sharp bends are avoided, and, as a result of experiment, with a consumption of 2.8 gallons of water per minute (at 1*s.* per 1,000 gallons), pressure by gauge 75 pounds per square inch, speed of 1,300 revolutions per minute; 0.055 HP. were obtained to drive a small lathe, the efficiency being 40 per cent. An ingenious form of governor was used, in which the increased speed by the centrifugal force of a weight, closed the orifice of escape and acted most effectually to check the

*Notes on Small Motors. Royal Society of Victoria, Oct. 9, 1879.

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racing and variation in speed, reducing the water used from 2.8 gallons per minute in full work, to 0.75 gallon when all the machinery was disconnected. There are numberless cases in which such a motor as the foregoing might be advantageously employed in towns, and where its use would compare favorably in efficiency with some of the engines at present chiefly employed and known as "water-pressure engines."

The form of water-pressure engine which is almost universally adopted for obtaining rotary motion is the oscillating type. A sectional view is shown in Fig. 15 of Haags' engine, which is extensively used on the continent, and is largely supplied by Schmid, of Zurich, where small water motors are used to the number of one hundred and thirteen, as alluded to by Mr. E. Matheson, M. Inst. C. E.* The action of the engine is extremely simple. The oscillation of the cylinder about its center alternately opens the opposite ends of the cylinder to the supply and exhaust of water. There seems to be a large amount of clearance by the long ports which would entail waste, but otherwise the engine is cheap and efficient. It is being introduced into this country by Messrs. Bailey and Co., of Manchester. Another form is Rambottom's patent, of which a general view is shown in Fig. 16. This, from its small first cost and simplicity of action, is at present the most extensively used in this country. Three cylinders oscillate about their lower extremities, and work upon a hollow cast-iron pipe, which is divided into two parts by a vertical diametral partition running its whole length. One side conveys the water under pressure to the cylinders by ports, which, when the cylinders are in an inclined position, communicate with corresponding ports in their basis; in a similar manner the other side conveys away the water when the cylinder is inclined in the opposite direction. Experiments were made with a dynamometer upon two of these, through the kindness of Mr. Camp, of Bristol, the inventor of hair-brushing machinery, and which was used for that purpose, the other being erected at The Institution of Civil Engineers, Great George Street, for driving the ventilating and warming apparatus. The annexed table gives a tabulated result of the experiments, from which the curves (Fig. 17) have been constructed.

Fig. 15.

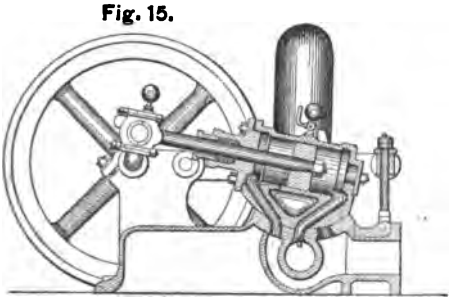


Fig. 16.

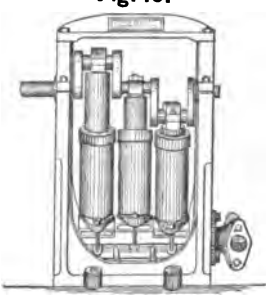
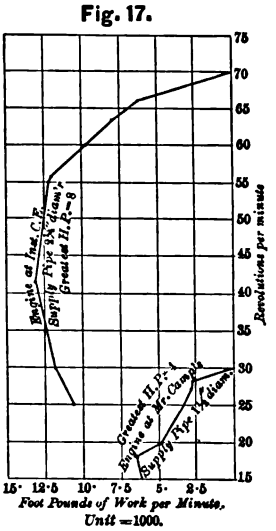


Fig. 17.



* *Vide* Minutes of Proceedings Inst. C. E., vol. xlix. p. 35.

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The pressure of the water gauge was taken with every change of load on the dynamometer; but since the gauge was fitted by a pipe at right angles to the pipe, and some feet from the engine, it would not be right to assume this as the pressure in the cylinders; the flow of water past an orifice being well known to affect the pressure in a channel from that orifice. Therefore, no deductions are drawn as to the efficiency of the motors at any but the lowest speed; for it was found that the cylinders, according to the reading of a water meter in the first-mentioned case, did not fill with water at much higher speed. But the supply pipe in that case was 1½ inch in diameter, by reason of a decision of the Waterworks Board of Bristol; while in the second case the diameter was 2¼ inches, or considerably more than twice the sectional area. This accounts for the differing results in the two cases, and the consequent very different curves, the engines being exactly the same in every other respect, the length of stroke being 9 inches, and the diameter of the rams 3½ inches.

EXPERIMENTS WITH RAMSBOTTOM WATER MOTOR.

Water motor at Camp's, Bristol, D.HP.=0.4.. ..	Revolutions.	15	18	20	24	27	28
	Pressure.. ..	60	50	45	40	34	30
	Foot lbs....	12,257	12,728	9,428	7,512	5,476	5,280
Water motor at Inst. C. E., London, D.HP. = 0.8.....	Revolutions.	25	50	42	48	55	
	Pressure....	43	40	35	30	25	
	Foot lbs....	21,214	23,570	26,400	25,646	24,420	
Water motor at Inst. C. E., London, D.HP. = 0.8.....	Revolutions.	56	58	60	63	66	
	Pressure.. ..	24	24	23	23	22	
	Foot lbs....	23,084	20,050	18,856	15,840	12,446	

The curves drawn from this table show revolutions as abscissæ and work in foot-pounds per minute as ordinates. The best results obtained in the first case were at the cost of about 2*s.* 10*d.* per HP. per hour; in the second case, at the cost of about 2*s.* 4½*d.* per HP. per hour. These figures were calculated from the greatest work produced, which corresponded to about the highest efficiency; taking the prices charged for water to Mr. Camp at 1*s.* 2*d.* per 1,000 gallons, and to The Institution of Civil Engineers at 1*s.* per 1,000 gallons. Of course the cost for water is much less than this in some towns, being, according to Mr. Hastie, in Glasgow, 4*d.* per 1,000 gallons, at a pressure of 50 pounds per square inch, and in Greenock, 5*d.* per 1,000 gallons, at 120 pounds per square inch; but still the prices, as compared with the cost of a gas engine at 1*d.* per HP. per hour, are high, and in the case of the some engines of a different kind driving the bellows of a large organ in Bristol, the rate is still higher. There is a considerable difference, however, between 5*d.* for 1,000 gallons at 120 pounds pressure and 1*s.* 2*d.* for the same quantity at 60 pounds, the former being 5.6 times as cheap. In Greenock it is found convenient to use water motors for many purposes, especially for intermittent work, such as hoisting.

An important question, and one that has often been raised, with regard to the use of water for the purpose of developing motive power, is the waste sustained by a varying load; for the non-expansive nature of water causes a full complement to be used at each stroke of the engine, whether the load be great or small. This subject was discussed in the paper of Sir W. Armstrong with regard to cranes, where it is said: "It is far less important to consider economy of fuel in the engine, than simplicity of construction in the cranes."* But the arrangement of cranes referred to was not automatic. In the discussion which fol-

* *Vide* Minutes of Proceedings Inst. C. E., vol. I., p. 78.

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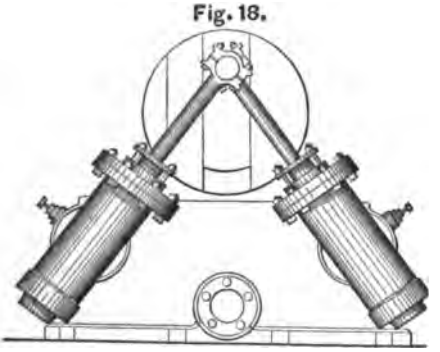
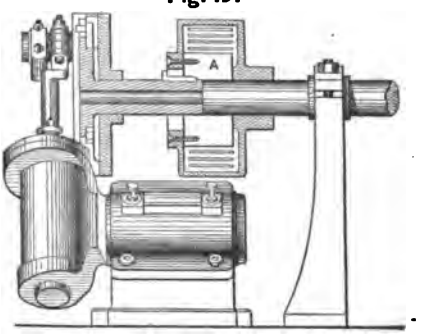
lowed, Mr. Duckam, M. Inst. C. E., showed the considerable loss which might be entailed, and referred (without contradiction) the cause of the objection of Sir W. Armstrong rather to "the necessity of depending upon the intelligence of the workmen, which was far more variable than the crane power." Now, in a recent invention of Mr. Hastie, of Greenock, this difficulty is overcome for water moters by using an automatic appliance of admirable design and simple in principle, thereby meeting the objection above quoted, which of course applied to all water engines. It may be briefly described as a means of varying the quantity of water used by a flexible connection between the power and the resistance, which principle seems capa-

Fig. 18.



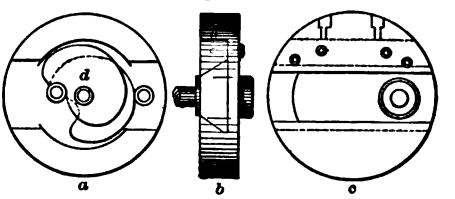
ble of the widest application. From the curves and tables already given it will be seen how much power is lost at the high velocity of the motor which ensues when the supply of water is not regulated to the load. The invention provides for this in the following manner: Fig. 18 shows a front elevation of the two-cylinder form, the cylinders oscillating about their middle point. The piston rods are attached to a crank pin, which slides in or out on the crank plate so as to alter the stroke according to the work to be done. Fig. 19 is a sectional view, showing a drum A, which is attached at one end to a hollow shaft driven by the crank plate, and communicates motion to the solid shaft by means of a spring, of which there are three forms, according to the degree of force transmitted, but which in the present and simplest case is like the spring of a watch. The action is thus: Suppose no load on the machine, then the spring will be uncoiled and the relative positions of the crank plate and solid shaft will be such that the cam shown in *a*, Fig 20, which is driven by the solid shaft, will allow the crank pin to approach near the center of the shaft, and so a small stroke will result, and a consequent small consumption of wa-

Fig. 19.



ter; but if a load be put on the engine, the effect will be transmitted by the solid shaft to the crank plate through the spring, which will be proportionably coiled up, the relative positions changed, and the crank pin driven out by the cam so as to increase the stroke, and consequently the amount of water used to a proportionate extent. In some experiments made by Mr. Kinipple, M. Inst. C. E. engineer to the Greenock Harbor Trustees, 7½ gallons of water were used in a hoist with the chain alone, 10 gallons with 427 pounds, the amount of

Fig. 20.



water increasing with the load, until 22 gallons were registered for raising 1,193 pounds.* Brotherhood's three-cylinder engine has been successfully modified for use as a water-pressure engine, and a description of its action, as well as

* *Vide* Institution of Mechanical Engineers. Proceedings, 1879, p. 487.

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drawings of it, are given in a paper by Mr. Tweddell, M. Inst. C. E., read at the Cardiff meeting of the Institution of Mechanical Engineers.*

So far no results from the second of the two sources, viz., water under accumulator pressure, have been given; but taking the average pressure as between 700 pounds and 800 pounds per square inch, and the charge when sold between 3*s.* and 4*s.* per 1,000 gallons, it is evidently far more economical. This question has been so fully discussed by Mr. Robinson in his paper, and the prices of water power from the principal dock systems so completely stated, that only the average cost need be quoted, being 1.26*d.* per 100 foot-tons of work, taking 80 per cent. as the efficiency of water. This corresponds to about 1.14*d.* per hour per HP., but of course the efficiency of 80 per cent. could only be obtained for large motors, and would certainly not be much more than half this for small motors; but even this compares favorably with the use of water from the town mains. It is in the use of high-pressure water for varying loads that an automatically regulating engine, such as the one above described, is found to be economical; and this at such rates as 4*s.* per 1,000 gallons, as charged by the Hull Water-Power Company, is at once evident.

ELECTRICITY.

Although the precise nature of electricity is not yet determined, it is known to be a form of energy, and many of the laws which govern its application to the production and transmission of power are understood. Although it cannot be said to be at present to any extent thus practically applied in this country, yet in France its use for the latter purpose is already an undoubted commercial success, and there is every probability that its universal adoption, under certain conditions, is only a matter of time. Therefore it is highly important to compare it with the other agents, the word "agent" in this case not being taken to imply anything material. In order to do this, however, a rather different treatment of the subject will be necessary to that previously adopted, as the machines which may be used, or which are at present used for other purposes, will not be described, but an attempt will be made to present a concise view of the conditions under which electricity must be employed, and of the experimental results recently published, so that the above comparison may be made.

The original method of obtaining an electric current for the performance of work is analogous to the generation of steam in a boiler, fuel being used in both cases; but the energy represented by zinc, which is the substance commonly so employed, is only about $\frac{1}{10}$ of that which an equal weight of coal would produce. As the cost of zinc is about £25 per ton, and of coal only about 10*s.*, the energy obtained from the former is about five hundred times as expensive as from the latter. However, as the efficiency of a small steam engine would be, perhaps, at the best $\frac{1}{10}$ that of a small electric engine, though often nearer $\frac{1}{20}$, the final cost of the work performed would be from fifty to twenty-five times as great.

These figures suffice to show why this method of producing electricity has been abandoned where power is required, and unless some cheaper substance than zinc can be obtained for the purpose, it is never likely to be re-adopted. Nevertheless, ever since the discovery of Oersted (1820), which led to the manufacture of the first electro-magnetic motor, there has been a continual production of such machines, though no attempts to apply them on a large scale have been made since the experiments of Jacobi on the Neva in 1838, whose engine developed about $\frac{3}{4}$ HP. Yet, for many small purposes, they have been adopted, especially in France, for working ruling machines, sewing machines, &c.; but it is a significant fact that the electric pen, in which an engine is actually present, though for a purpose requiring a minimum force, is about their only present use as motive power, even the manufacture of the latest and very efficient Howe electric machine, invented to drive sewing machines and developing about $\frac{1}{8}$ HP., having been now given up.

There is another mode of producing an electric current, viz., by the expenditure of energy from any available source, such as steam or water power, on a magneto or dynamo-electro machine. The

* *Ibid.*, 1874, p. 173.

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current so produced is identical in nature with that from a battery, but very different in cost—and upon this point turns the whole question of its possible introduction, for these are practically the only two methods of generating electricity. The latter would obviously only be used for the purpose under consideration, when the steam or water power producing it could not be directly applied, that is could not be obtained on the spot where the application of their energy was needed. This, therefore, reduces the question to the discussion of the efficiency of the transforming apparatus used; and upon the result, that is, upon the percentage of the useful work obtained of that given out by the prime mover, the use of electricity as a transmitter of power depends. In order to do this in a lucid manner the two actions will be discussed separately.

(1) The efficiency of the generator of electricity, giving the loss of power in the production of the current.

(2) The efficiency of the machine which re-transforms electricity into work.

Of course the resultant efficiency is the product of the two; but though, as is often the case, the two machines may be identical in construction, yet the efficiencies may not be the same, since the conditions under which they are respectively used are not identical; that is to say, the efficiencies of the operations are different.

(1.) The first has been made the subject of direct experiment by Dr. Hopkinson, Assoc. M. Inst. C.E., and others. In a paper read before the Institution of Mechanical Engineers by the former,* the results show an efficiency of $\frac{9}{10}$, exclusive of friction; and from the whole set of experiments Dr. Hopkinson deduces a mean total loss of 12 per cent. and of 13.8 per cent. respectively in producing the current; that is, the useful work represented by it is from 86-2 to 88 per cent. of the work applied to produce it. He quotes the results by Mr. Schwendler, M. Inst. C.E., and Mr. Trowbridge, the former obtaining 88 per cent., the latter 76 per cent. All these experiments were made with the machine of Siemens, which undoubtedly gives as high a result as any, and perhaps higher than some machines; but the fact remains, that a return may be obtained which, in connection with the comparison already made between the cost of boiler and battery power, renders the former, as applied in this way, immensely superior to the latter, and proves the loss in producing electricity to be less than in bringing either water or compressed air to a similar state of stored-up energy.

(2.) But the next point is to examine the further loss, viz., in turning the current so produced into work; and this is by no means so easily determined, nor does it yet appear to be a settled question. An electric current may drive either an electro-magnetic engine, or a magneto- or dynamo-electric machine, and the result is theoretically the same. The principle by which motion is caused is the attraction of two pieces, one fixed and the other movable, which may be either one or both temporary magnets, and with this effect: as long as the driven machine is at rest, the full force of the current is expended in overcoming the resistance of the circuit, but immediately upon the load being so reduced that a slow motion is the result, the needle of a galvanometer placed in the circuit will be deflected, showing a diminution of current strength. This is caused by the return current, which it is obvious—at any rate with a magneto or dynamo machine—must be produced immediately it begins to rotate, as it may be supposed to generate an independent current, opposing the original one. Now, the expenditure of energy in the first machine—or the consumption of zinc, whichever it may be, as either may be supposed to be producing the current—is thereby reduced; and this reduction will continue as the speed of the driven machine increases, the needle of the galvanometer showing all the while a fall in current strength. The load on that machine must be of course correspondingly reduced, and the theoretical limit is easily seen to be that point where there is no load at all upon it, the return current equal in strength to the original one, and therefore no current passing, and the velocity of the second machine equal to that of the first, and therefore driving it with equal force to that with which it is driven by it; or if a battery be used, the velocity of the driven machine would

* *Vide* Institution of Mechanical Engineers. Proceedings, April, 1879, p. 238.

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depend in a definite way on the battery, producing an equal and similar effect. These conditions it is of course impossible to realize, for, as it is evident that then no work is being done by the source, the friction of the driven machine in practice would prevent this limit being attained. But it is possible to conceive the friction being so reduced that the limit may be closely approached; although as the load is reduced, the useful work done will grow less, and will bear a decreasing proportion to the work wasted in friction. It becomes a most important point to consider the extent to which this can practically be carried—that is, what is the load and corresponding speed giving the highest efficiency?—and is, in fact, an answer to the question as to the amount of work reclaimable from the electric current. In the first place, it must be noticed that the work done at the two limits, viz,, when at rest, and when no current is passing and the machine has its maximum velocity, is zero; and it can be proved in several ways that, as might be anticipated, the greatest amount of work in a given time is realized half-way between these limits. In fact, when the return current is just equal to the forward one, then the efficiency is $\frac{1}{2}$, or the work reclaimed is 50 per cent. This fact was stated in a paper read before the Institution* by Dr. P. Higgs and Mr. R. Brittle, Assoc. MM. Inst. C.E.; in which it was also said that, "supposing two equal machines arranged for the transmission of power, the amount of work reclaimable from the second machine will be 50 per cent. of that employed upon the first, and the number of revolutions of the armature of the second machine corresponding to the maximum of work reclaimed will be half the number made by the first." Experiments were made with a steam engine as prime mover, which showed in one case as much as 49 per cent. of returned energy, at which point the number of revolutions, as nearly stated above, was 1,400 for the driving machine, and 691 for the driven; in other cases the maximum percentage of work returned also corresponded nearly to these conditions, and curves were constructed showing the maximum percentage of work as ordinates, and the revolutions as abscissæ. If, however, 12 per cent. of the work be lost in obtaining the current, then, according to the above theory, only 44 per cent., which is half the remainder, is the amount of work finally reclaimable. Work reclaimed was measured by a dynamometer, which does not register the work done against the friction of the second machine; and this, taken in conjunction with the significant shape of the curves, which all show a more gradual slope as the revolutions increase, after the highest ordinate, and when the ratio of work lost in friction is also increasing, may put the point of maximum efficiency beyond that where the revolutions of the second machine are one-half those of the first, and nearer the point suggested by Dr. Siemens, viz., two-thirds of this. This important question was discussed by Professor W. E. Ayrton, Assoc. M. Inst. C.E., in a discourse delivered to the working men of Sheffield, at a meeting of the British Association for the Advancement of Science in 1879, on "Electricity as a Motive Power." He considers that, by obtaining a high speed with the first machine, and also with the second running with a light load, "the combined efficiency of the arrangement can be made to closely approach the square of 0.86, and not merely one-half, as commonly supposed."* The high speed being necessary to develop a reasonable amount of work in a given time with a light load, the above conclusion really means that the only work lost by the transformation of the current into work need only be just the same as in the production of the current. This being possible, even in theory, would enable it to be predicted that the 49 per cent. already referred to could be considerably increased by improved mechanical construction.† Some experiments by Professor W. C. Unwin, M. Inst. C.E., the drawings and data of which he has kindly placed at the disposal of the author for publication, seem to have a decided bearing on the subject, as they appear to indicate that the theory which requires a light load, in order to obtain a high efficiency, is modified in an important manner by the friction of the

* *Vide* Minutes of Proceedings Inst. C.E., vol. lii., p. 86.

* *Vide* "The Electrician," vol. iii., p. 191.

† Since the foregoing was written, Dr. Siemens has stated in a lecture at the Royal Institution, that 60 per cent. had been obtained.

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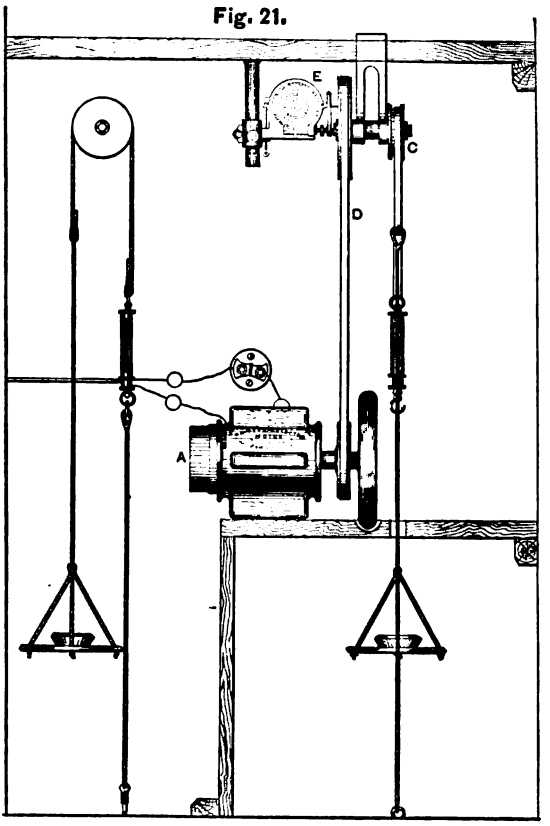
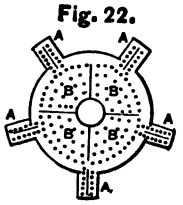
machine itself. The current was obtained from a battery, but the conclusions as to the driven machine seem in no way altered. Fig. 21 is a general view of the

Fig. 21.



arrangement adopted; A is a Howe electric motor, of which Fig. 22 is a sectional sketch showing its general design. It consists of a revolving axis, on which

Fig. 22.



are four electro magnets, BBBB, and which by means of five fixed electro magnets, AAAAA, receives twenty attractions in a revolution. The motor drives a brake wheel, C, by means of a band, D, and also an apparatus, E, for recording the number of revolutions. The brake designed by Professor Unwin, although it appears to have been previously used by Mr. Bramwell, is a most convenient one for small powers, and merely consists of a band passing over C, having a Salter balance on one side, and a scale pan on the other, a side view of this being shown in the figure to the left. Then

P = Force in pounds on brake-rim = pull in balance − weight of and in pan.

V = speed of effective pulley-rim in feet per minute.

P × V = foot pounds per minute.

The time of 100 revolutions was taken by a chronograph in fifths of seconds, and a table is given of the results of six series of experiments of batteries of various kinds and powers. In the three

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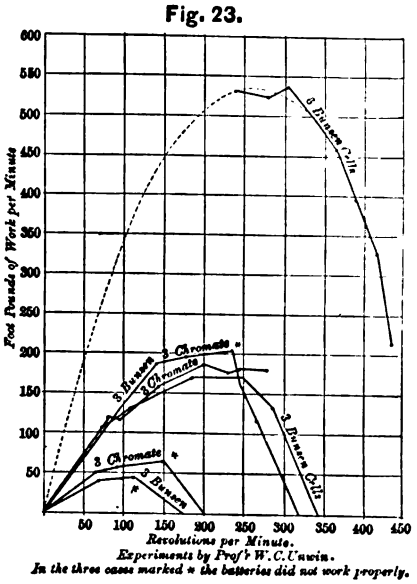
marked * (Fig. 23) the batteries did not work properly; still the results are given with the others as leading to the same conclusion. From the tables the experimenter constructed the curves shown in Fig. 23, which have for ordinates the

Fig. 23.



Experiments by Prof'r W. C. Unwin.
*In the three cases marked * the batteries did not work properly.*

actual work done in foot-pounds per minute, and for abscissæ the number of revolutions per minute.

Now, according to theory, if there were no friction in the machine, the work should vanish for a number of revolutions just double that at which the work was greatest; that is to say, the ordinate should become zero at a distance from the origin just twice that at which it is a maximum; but in every case this, as would be expected, takes place at a point not only less, but very considerably less, than twice this distance, which means, that at the higher velocities the friction due to the machine itself (assuming the friction due to the load to vary with the load) bears a considerably increasing proportion to the useful work done, and finally causes the latter to vanish, so as to affect in an important way the theoretical efficiency. Assuming the attractions to act so that their influence on the friction is balanced, and the effective circumference of the pulley to be 1 foot, then an expression similar in form to the following will obtain;

If W_1 = load,
W_2 = load due to machine itself,
n = number of revolutions per minute,
μ = some multiplier for friction,

then $n\,[W_1 + \mu(W_1 + W_2)]$ = work done per minute.

Now, as n is increased, W_1 must be diminished, and finally when W_1 vanishes and n becomes N,

$$N\,\mu\,W_2 = \text{work done};$$

which may be considerable, but is all wasted in friction, this quantity being most important in the question of the possible highest efficiency.

Referring to the curve with six Bunsen cells, the maximum useful work is seen to correspond to 300 revolutions. Now the reading of the galvanometer, which was taken for each experiment, when properly reduced, shows a reduction in current of nearly one-half, thus proving this to be nearly the position of maximum total work; and accordingly, by theory, the efficiency should be also nearly one-half; but assuming 12 per cent. of the work to be lost, as already explained, in obtaining the current, the greatest return of work would be one-half of 88 per cent., or 44 per cent. Now the efficiency would approach 88 per cent. as the revolutions approached 600, but the useful work vanishing at 430, the highest possible efficiency could not exceed $\frac{88 \times 430}{600} = 63$ per cent. But the effect of friction is such that in the present case anything like this is quite unattainable.

The foregoing reasoning cannot pretend to do more than point to the practical bearing that the friction due to the weight of the motor, and its connection, by bands or otherwise, with the work to be done, has upon the efficiency at high velocities, showing that for small powers it is likely to be nearer 50 per cent. than 80 per cent. Messrs. Higgs and Brittle failed to obtain more than 49 per cent., their mean result being 44⅛ per cent. There is a further point to be noticed in connection with the effect of reducing the scale of operations, viz., that with six Bunsen cells, the best results were nearly three times as great as the best results with three, instead of twice, given by

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applying Ohm's law; and again, that the number of revolutions for which the useful work was a maximum, and also the number for which it became zero, was less as the battery power decreased, showing that the ratio of loss by the friction of the machine increased with lighter loads and higher speeds.

Still it may be assumed that an efficiency of 50 per cent. may be expected, even on a small scale of application, and this compares favorably with that obtained with other agents. For instance, it is greater than with compressed air, and, under the conditions now considered, than with water; whilst the necessary use of pipes, respectively air or water tight, is certainly more expensive than the use of wires, and in point of convenience also the advantage is greatly on the side of the latter; so that it is probable that the use of electricity will, before long, be applied for many purposes to distribute power and to take the place of the other agents, and even of lines of shafting.

Section III.

In the foregoing section the efficiency of each agent has been stated, as far as possible in terms of the fuel used, but this is only one factor in the question of their relative economy, which includes:

- First cost.....
  - Cost of agent and its efficiency.
  - Cost of attendance, repairs, etc.
- Expense of working
  - Outlay on apparatus, taken in connection with probable durability.

Now, in the present state of small motors, which is not a settled one, the cost of apparatus for some agents, such as gas or electricity, has, it is to be hoped, by no means reached a minimum; while for others, steam, water, and hot air, competition has brought prices to a point below which they cannot be much reduced. Moreover, the question of durability and repairs is with some of them difficult to settle. Again, the same agent may have very varying efficiencies in different motors; while, lastly, an examination of the price lists will show how different are the prices quoted by various makers for the same kind of engines and of the same nominal power. This latter discrepancy partly arises from the present unscientific procedure of defining "nominal" apart from "actual" HP., the evils arising from which would be considerably modified if the pressure, number of revolutions, and the actual power were to be advertised as well as the price, as done by Mr. Brotherhood and others; this would enable the purchaser to judge for himself, and thereby avoid the anomalous varieties in advertised power which visitors to agricultural shows must have noticed in connection with some small motors, and which must be quite inexplicable to the uninitiated. Variation in quality and workmanship has also, of course, a good deal to do with the difference alluded to. For the foregoing reasons it seems impossible to give a tabulated, or even concise, comparison of the agents, as far as their relative cost and efficiency is concerned: but this is, after all, not so important on a small scale as on a large one, the differences not being so great as to make this, in the majority of cases, the predominant one, which is more often rather one of suitability, and which can only be discussed by considering the objects for which the power is required, many of which have been already incidentally mentioned, and which may require either constant or intermittent use, and may give security, regularity, cleanliness, or compactness more or less importance. Therefore, as stated at the commencement of the paper, it seems most satisfactory to discuss their relative advantages in connection with the purposes to which they are applied. In order to do this it must be remembered that the great increase in the number of small motors is the natural result of the progress of applied science, by which the substitution of machinery for manual operations tends to bring about a displacement of muscular effort by the application of natural sources of power; but it is important to observe that this is taking place under two different conditions.

(1.) Where an extensive source of power is not directly available, as in small isolated factories, in shops, private houses or in the country.

(2.) Where—as on board a steamship, or a large factory, or in a system of docks—there is already a supply of the

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working agent on a large scale, often for driving a prime mover of considerable size, which supply may in many ways be turned to use by small motors, for superseding manual labor.

These conditions may materially modify the conclusions as to the choice of a small motor. For instance, the steam engine which is less economical than the others was shown to be so, chiefly on account of the small boiler, but may give a very different result if supplied with steam from a large and efficient one, where, in addition, one attendant only is required, for perhaps a score of engines instead of for the single small one; so that these two cases will be treated separately.

(1.) A special aspect of the former has been considered in the pamphlet by Peter Hell, already referred to, in which the writer earnestly advocates the increased application of small motive power, now to be obtained at moderate cost, for the revival of the domestic industries of Germany, which have suffered so severely from the introduction of large factories with powerful engines. He takes as a particular example the case of the weaver, who might, he considers, be restored to his former position of comfort, by the use of a small cheap motor, and "might be himself able to employ his supposed deadly enemy, the mechanical loom."* He also deals briefly with the use of small motors for agricultural purposes. This accounts for the conclusion arrived at by him, viz.: that the only suitable agents are gas and hot air; his opinion being that the motors of Otto and Langen, for the former, and Lehmann's "closed" and the Hock "open," for the latter, are the most efficient. For what has been shown, there is no doubt that the conclusion, as far as the agents themselves go, is, under the special circumstances, a sound one. For small manufacturers, for private individuals, in shops, &c., and for the many subsidiary industries carried on in the large towns of this country, the recent silent gas motors have supplied a long-felt want, this being abundantly testified by their remarkable sale. Gas is immediately accessible, no special attendance is required, the engines work in the same room with the other machinery, performing the most delicate work; they are clean and noiseless, and always ready at a moment's notice to commence work. Some of these advantages pertain to the use of hot air, and one is certainly common to both, viz.: the obviation of all danger of explosion, a consideration of great importance. But the great disadvantage of hot air is the limited power which small engines develop; though for light purposes, where gas cannot be obtained, the hot-air engine of Rider or Lehmann forms an efficient substitute. In analyzing the list published by Messrs. Crossley Brothers, of the silent gas engines sold by them during the two years or so since their introduction, 40 per cent. of the 3½ H.P. went to small manufacturers, including boot and shoe manufacturers (of which six went to Bristol alone), jewelers, turners, and for sawing, weaving, clock making, spring making, and aerated water machinery, and for many like purposes; while 31 per cent. of the 1 HP. were supplied for printing and lithographing machinery, for which, especially the latter, the absence of dust and dirt is a desideratum. For the foregoing purposes and for lifts for hotels, infirmaries, warehouses, &c., the slight attendance required with gas or hot air is a great advantage, a small steam engine being really a troublesome thing, the regulation of the water to the boiler, &c., requiring almost the full attention of one man. Water from the mains may, however, be conveniently applied to all the purposes mentioned where, as in Glasgow or in Greenock, it is cheap and under considerable pressure. It possesses all the advantages already claimed for gas or hot air, with the additional one of absolute immunity from the danger of causing a conflagration. Mr. Hastie, of Greenock, in a letter to the author, states that "the purposes to which water motors are applied in Glasgow, are as follows: Hoists, very extensively; by carpenters, for working circular saws; by bookbinders, bakers, hairdressers, at churches for organ blowing, in public institutions for washing and wringing machines, and also for chaff cutting and meat mincing." He goes on to say that the expense for water is in some cases very little; in one case, to a printer, it was 9s. per quarter, and in many cases in Greenock the minimum rate charged

* "Klein-Kraft-Maschinen," p. 9.

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by the water company, viz.: 20*s.* per quarter is not exceeded. However, these liberal terms, unfortunately, cannot be obtained in the majority of large towns, and then gas is generally the best agent.

For private houses, laboratories and shops, where the power required is often little more than nominal, and its use intermittent, the small first cost of a water engine (the Ramsbottom being about £30), in conjunction with the other advantages, may be often sufficient to more than counterbalance the high rate of the water from the mains; but for such purposes, especially when a water meter is used, the custom of charging a high minimum rate, often considerably exceeding the actual cost of the water used, stands in the way of its adoption. In one case in Bristol a minimum rate of £20 per annum is charged for three pairs of small engines, which are only required for six or eight hours per week. In the country a small fall of water from a stream may often be used for pumping purposes, when a water wheel or small turbine affords a very efficient method of utilizing it.

One application of gas not yet mentioned is that to the electric light. It is found for some purposes more economical to use gas indirectly to produce illumination, rather than to use it directly. From the paper of Mr. Alexander Siemens, read April 2d, before the Society of Telegraph Engineers,* it appears that a saving of from 47 per cent. to 87 per cent. is thus obtained. In the British Museum a saving of 60 per cent. is effected by the substitution of electric light for gas; but in this case the motor is a steam engine, and it is necessary to keep the fires alight all day in order to be ready at a moment's notice, the cost of attendance being 1.2 of the light itself. In the Albert Hall the saving is, in the same way, 66 per cent.; so that, whilst the absolute cost of steam is perhaps less than that of gas, its convenience and readiness of application are also less. Where gas is not available, then steam, supplied generally by portable engines, must be used.

For agricultural purposes gas is out of the question; and where water power is inaccessible, as is generally the case in this country, either steam or hot air must be resorted to. For purposes requiring much power—as thrashing, plowing, &c. —steam must hold its own; but for light work, such as fodder cutting and pumping, the hot-air engine is beyond all doubt the most suitable, that of Rider, which is semi-portable, and requires no skilled attendant, being often used.

For purposes where small portable motors are required—as for contractors' work, for cranks, for rather large pumps —small vertical or horizontal steam engines and boilers will no doubt always be used, from the fact of the considerable power developed by them in comparison with their weight and size.

(2.) In the second division, where a source of power is already at hand, the circumstances are altered. On a steamship or in a large factory, where there is an abundant supply of steam, produced economically, because on a large scale, no agent can compare with it. In the first instance, viz., on a steam ship, where the area of distribution is limited, this is especially the case; and for steering, hoisting the cargo and anchor, turning the capstans and windlass; for ventilating, pumping, &c., small auxiliary steam engines are invariably used, when these duties are not performed by hand. In the second case, it is often found to be more desirable to use auxiliary engines, for driving machines—as for instance the centrifugal machine in a sugar house, or the punching and shearing machines of a shipbuilding yard, both these being formerly driven by shafting; but to the former small Brotherhood three cylinder engines are often now directly applied, and the fluctuation in speed on the main engine, caused by the intermittent use of the machine, is thus avoided, and a much smaller one required.

Again, in a system of docks where an accumulator if used for supplying water under great pressure for large cranes, it is more convenient to use small high-pressure water engines than any others. For instance, in connection with the Cumberland basin, Bristol, there are twenty-three sets of small oscillating water engines, supplied by Sir W. Armstrong, there being sixty-six small cylinders used, averaging not more than 2 or 3 inches in diameter; these are applied to move the bridges, gates and capstans

* *Vide* "Journal of the Society of Telegraph Engineers." Vol. IX., p. 89.

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connected with two docks, and are easily and rapidly put into operation. During the last two winters of severe frost, not a single accident has happened through the bursting of pipes, and the suitability of water for this purpose is undoubted, In a large system of warehouses, such as at Birkenhead, water power is certainly to be preferred to any which necessitates the introduction of fire or light, and at Hull the system has received considerable development.

The conclusions are, briefly, that gas is generally to be preferred as an agent for small manufacturing operations—for hoists in buildings, &c.; but water and hot air both have decided advantages—the former, when obtainable at a low rate, the latter for light purposes, when neither of the others are available. For private houses, shops, &c., water, even at a dear rate, may often be applied. The proper applications of steam have been indicated, and though likely to be more and more superseded by the other agents in the foregoing cases, particularly by gas, yet there is a large field in which small steam engines must continue to hold their own.

In conclusion, the author wishes to record his thanks to Professor Unwin, for the data and suggestions supplied by him; to Dr. Main, Professor of Mathematics and Engineering, University College, Bristol, and to Messrs. C. D. Selman and A. W. Metcalfe, students; as well as to those gentlemen who have allowed him to test their engines, or have supplied him with information.

THE FLOW OF GASES THROUGH TUBES.

GENERAL AND PRACTICAL PROBLEMS.

By S. W. ROBINSON, Professor of Mechanical Engineering, Ohio State University.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE great demand of late years for compressed air transmitted long distances, through tubes, has created a necessity for a proper basis of calculation for the use of engineers in practice. The most trustworthy means yet produced appears to be a table obtained from experiments made under the Italian Government about forty years ago. And, indeed, this table appears to have failed of application in many cases for want of publicity. The answers to some great questions have been so delayed, for want of ready means for calculation, as perhaps to have caused the failure of some important works.

Formulas have, however, existed which, though not fully correct, would have given results not far from the truth. It is, perhaps, forty years, since European engineers accepted the doctrine that a formula, suitably expressing the conditions of flow of one fluid in a tube, is applicable to all others. A statement of such doctrine was made in a supplementary part of an important French work on hydraulics, published nearly forty years ago, by M. D'Aubuisson.

This principle may now be unhesitatingly accepted as truth for all cases where the conditions of the fluid, as regards density, remain the same. That is to say, when the density remains sensibly constant, as in water, and as in illuminating gas, very nearly; because the absolute pressure remains one atmosphere within about one per cent. the ordinary formulas of hydraulics will apply. When the density varies according to any certain law expressed as a function of distance along the pipe, another set of formulas will apply, and for all fluids under this law. These formulas will differ from those of hydraulics. Again another law of density will give another set of formulas, &c.

The peculiarities just stated respecting laws of density are common to flow of gases through orifices as well. But for this there seems to be but two cases: 1st. When the change of pressure is so slight that the change of density may be neglected; and, 2d. When the change of pressure is so great that change of density is considerable, and the flow is to be considered as adiabatic. For the

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first the formulas of hydraulics for discharge through orifices will apply; while, for the second, they will not. But formulas for adiabatic flow have already been worked out, and are to be found in numerous works on heat.

But for pipes there may be an indefinite number of laws of density, among which we find three prominent special cases: I. Density constant. II. Density varying as for the adiabatic flow. III. Density varying as for constant temperature, and for assumed laws of varying temperature.

I.—This has already been referred to as that where the ordinary formulas of hydraulics for flow through pipes are applicable. These formulas, however, are usually stated with reference to head h, the same being the elevation of the free surface of water at the source, above the point where the water becomes free at the discharge. If the exit is submerged in a tank, then the level of the lower free surface is the lower point of head. This head is sometimes called dynamic head, because it measures that head to which the motion in the pipe is due. This head may be stated in terms of the statical pressure due to the difference of level and density of the fluid. It is equal to the height of a column of fluid with a unit's area of base, and with a density equal that of the fluid flowing, the weight of which is equal to the above statical pressure. That is, let p = the statical pressure and δ the density of the fluid flowing through the orifice or pipe. Then

$$h=\frac{p}{\delta} \quad . \quad . \quad . \quad (1)$$

But this pressure p may be a difference of two pressures. Thus suppose a horizontal plane situated at a distance below the free surface, both at the source and at the exit from pipe. Let p_1 be the weight of a column of the fluid of unit's area, supposed standing on this plane and reaching to the upper level. Similarly let p_2 be the weight of a column reaching to the lower level; then

$$p_1-p_2=p,$$

and hence

$$h=\frac{p_1-p_2}{\delta} \quad . \quad . \quad . \quad (2)$$

In gaseous fluids these pressures are more readily observed than h. For instance, suppose a receiver containing compressed air at 50 lbs. pressure per square inch, or 7,200 lbs. per square foot. Let this discharge by a pipe into another at 7,100 lbs. per square foot. The specific density of air at this pressure or weight per cubic foot is, say 0.32 lbs. Then

$$h=\frac{p_1-p_2}{\delta}=\frac{7200-7100}{0.32}=312.5 \text{ ft.}$$

In this example the fall of pressure, also of density, is a trifle over one per cent., and if that can be regarded as not giving cause for a change of final result which will be noticeable, this value of h may be introduced into the hydraulic formulas for computing velocity of flow of air for this case. The velocity of flow of the air will here be the same as that of water through the same pipe under a head of the same 312.5 ft.

The same expression for h is also applicable to the formulas for flow through orifices under small changes of pressure. Thus,

$$v=u\sqrt{2gh}=u\sqrt{2g\frac{p_1-p_2}{\delta}} \quad . \quad . \quad . \quad (3)$$

u being the coefficient of velocity. The density, δ, should be taken as that due to a pressure midway between P_1 and P_2, or to the pressure

$$\frac{p_1+p_2}{2}=p'.$$

Let $\tau'=461.2+t'$, be the absolute temperature of the flowing gas. Then according to the M. and G. laws

$$\frac{p'}{\delta\tau'}=\frac{p_0}{\delta_0\tau_0}$$

the quantities in the second member being taken at the melting point of ice.

Then

$$h=\frac{p_1-p_2}{\delta}=\frac{p_1-p_2}{p'}\cdot\frac{p_0\tau'}{\delta_0\tau_0}$$

$$=2\frac{p_0\tau'}{\delta_0\tau_0}\cdot\frac{p_1-p_2}{p_1+p_2} \quad . \quad . \quad . \quad (4)$$

The object of this modification of the expression is to facilitate the necessary account to be taken of the density, the values of the quantities at ice-melting temperature being usually found in tables.

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To obtain a rational expression for the flow of gases in pipes we have for the outset the well-known relation

$$R=f\delta A\frac{v^2}{2g}, \quad . \quad . \quad . \quad . \quad (5)$$

where R is the resistance to fluid friction of a fluid whose specific density is d, moving with a velocity v, along a surface of the extent A; f being the coefficient of fluid friction, and g the acceleration of gravity. In applying this to find the resistance to the movement of a fluid through a pipe, A is to be taken = the internal surface of the pipe in contact with the moving fluid. Hence $A=sl$, where s=perimeter of cross section and l=length of pipe. Also R=the pressure which has to be exerted against the end of the column of fluid in the pipe to force the tube-full along, making $R=(p_1-p_2)a$, where a=the sectional area of pipe. Hence

$$R=(p_1-p_2)a=f\delta A\frac{v^2}{2g}f=\delta sl\frac{v^2}{2g}$$

or

$$\frac{v^2}{2g}=\frac{a}{fsl}\cdot\frac{p_1-p_2}{\delta}=\frac{ah'}{fsl} \quad . \quad . \quad . \quad (6)$$

where v=velocity of fluid in the pipe, a=area of cross section, s=perimeter of cross section, and l=length.

This expression evidently takes account only of the resistance to fluid friction between the fluid in the pipe and the inside surface of pipe. In very long pipes this is the chief resistance, but in short ones the acceleration at the entrance to pipe has to be taken into account, that is, the work necessarily performed to produce v, if w = the weight of the fluid entering the pipe per second. This, multiplied by the height, or head, h, gives a quantity of work per second,

$$wh''=FS=\tfrac{1}{2}MV^2=\frac{W}{2g}V^2$$

or

$$h'=\frac{V^2}{2g} \quad . \quad . \quad . \quad . \quad (7)$$

where the relation $FS=\frac{1}{2}MV^2$ is a fundamental formula in mechanics applicable to the present case as expressing the relation between the force F, or weight W; space S, or height h; and resulting velocity V of the mass M of the weight W of fluid, which is moved per sec. from a condition of rest in the reservoir, into the pipe where it has the velocity V. But this velocity is the theoretic, the actual velocity v, being the theoretic, multiplied by the coefficient of velocity u, found by experiment. Hence actual velocity

$$=uV=u\sqrt{2gh'}=v \quad . \quad . \quad . \quad (8)$$

The heads appearing in (6) and (8) are different, one being consumed in overcoming friction, and the other in producing motion. The sum of these should evidently be taken to obtain the whole head for short pipes, where the latter is too great to be overlooked. Adding, we get

$$h'+h''=h=\frac{v^2}{2gu^2}+\frac{fsl}{a}\frac{v^2}{2g}=\left(\frac{1}{u^2}+\frac{fsl}{a}\right)\frac{v^2}{2g}$$

whence

$$\frac{v^2}{2g}=\frac{h}{\frac{1}{u^2}+\frac{fsl}{a}} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

a formula for a pipe, however short or long; when very long the first term in denominator may be neglected, and the equation becomes (6). When the pipe is very short the 2d term becomes inconsiderable and the expression reduces to (8) or (3). In using this equation h is the same as h in eq. (4), by which the proper head is to be found.

This is a general formula for all pipes for the present case, that is to say, pipes of uniform cross section, and for conveying fluids of invariable density. It therefore is a general formula for hydraulic pipes, for rivers and canals: for pipes distributing street gas, for air ducts employed in ventilating buildings, for galleries and passageways in ventilating mines, for conveying steam and air at high pressure where the pressure falls but slightly and temperature remains constant. The formula includes all the various hydraulic formulas ever given for pipes and rivers. Paradoxical as this may at first appear, it becomes evident enough when it is noticed that all the discussions of hydraulic formulas for pipes and rivers are, in effect, simply discussions of the coefficient of fluid friction f. These discussions make it appear that f is not absolutely constant, some contending that it varies slightly with velocity, others with the radius of pipe, others with radius and velocity, &c. For instance, according to

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Coulomb, $f=a+\frac{b}{v}$.

Weisbach, $f=a+\frac{b}{\sqrt{v}}$.

Darcy & Bazin, $f=a+\frac{b}{r}$.

Eytelwein & Leslie,

$$f=a.$$

Neville, $f=\left\{a+b\left(\frac{f}{v}\right)^{\frac{1}{2}}\right\}^2$.

Gauguillet & Kutter,

$$f=1\div\left(a-\frac{ab}{\sqrt{r}+b}\right)^2.$$

Du Buât,

$$f=1\div\left(\frac{\frac{b}{\sqrt{r}}}{1-cv\sqrt{\frac{f}{r}}\log\left(\frac{r}{v^2f}+e\right)^{\frac{1}{2}}}-\frac{i}{v}\sqrt{\frac{r}{f}}+\frac{j}{v\sqrt{f}}\right)^2$$

from which it might at first appear that f may have almost any value or expression. But in practice it is found to be slightly variable, its extremes being found under extreme conditions, such as very large or small velocities, or of cross sections of current. From this fact it would appear that its expression should be a function of both v and r, as indeed we find it in the last above, and this may explain why this formula of Du Buât, though one of the earliest, is still recognized by some writers as one of the most truthful yet produced. Its complexity interferes with its use in practice, but tables may be computed for f, by aid of which its advantages become available. The constants a or b, &c., in the expressions for f, are not all the same numerically; r being the "mean radius."

A good approximate value is

$f=.005$ or $.006$ ordinarily.

To indicate the application of eq. (9), let it be required to calculate the fall of pressure between the steam chest and steam cylinder of an engine when that fall is not great. The formula (9) does not account for the curves in the passage, the loss of pressure due to bends being determined by a separate and independent calculation. Here the pipe is too short to admit of neglecting the 1st term in the denominator, the value of the coefficient of velocity u being in this case that for an ajutage, and $= .82$. Taking $f=.006$ $2g=64$, and $h=\frac{p_1-p_2}{\delta}$, we have

$$\frac{v^2}{64}=\frac{\frac{p_1-p_2}{\delta}}{\frac{1}{(.82)^2}+.006\frac{sl}{a}}$$

$$p_1-p_2=\frac{\delta v^2}{64}\left(1.487+.006\frac{sl}{a}\right)$$

$$=\frac{\delta v^2}{10700.}\left(248+\frac{sl}{a}\right) \quad . \quad . \quad . \quad (10)$$

for a formula adapted to steam cylinder passages, where $v=V\frac{A}{a}$ = the velocity of the steam as it flows along the passage.

By these formulas p_1-p_2 will be in lbs. per square foot. δ the weight of the flowing steam per cubic ft., l the length of the passage in feet, a the sectional area of the passage in square feet, S the perimeter of the section of passage in feet, V the piston speed of engine in feet per second, and A the sectional area of the steam cylinder in square feet.

As an example to illustrate use of (10) take a piston speed of 300 ft. per minute, or 5 ft. per second = V, A=1 square ft., $a=\frac{1}{7.2}$ square ft. = 1×7.2 inches, = 7.2 square inches, $l'=1$ ft., $s=16.4$ inches = 1.367 ft. Take the steam pressure at 75 lbs. per square inch absolute. Then

$\delta=\frac{1}{5.67}=.1764$, $v=100$, and

$P_1-P_2=$ 40.9 lbs. per square ft.
$=0.284$ " " " inch.

The velocity being here 100 ft. per second, the result corroborates the statement of Rankine's work on the steam engine, that this velocity causes no very considerable fall in pressure.

II. For flow adiabatic, or where no heat is transmitted to the gas while flowing, and for great fall in pressure, it will be necessary to adapt a formula to a very short portion of the pipe and take the sum of the effects due to all the

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parts of length. Formula (9), neglecting the resistance due to the orifice of entry, becomes

$$\frac{v^2}{2g}\frac{fsl}{a}=h=\frac{p_1-p_2}{\delta} \quad . \quad . \quad . \quad . \quad (11)$$

Applying this to a very short pipe whose length is dl, we will obtain a small loss of head due to it of $p_1-p_2=dp$, and we have

$$\frac{v^2}{2g}\frac{fs}{a}=dl\frac{dp}{\delta} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

a general differential equation for pipes conducting fluids of varying density. Though δ is to be regarded as a constant for the length dl, it is to vary for greater portions of pipe length according to the assigned law of density. The velocity in the pipe will also differ from point to point, and hence v is a variable. By expressing these variables as functions of l or p, the integration may be performed and the desired formula obtained.

In the present case of adiabatic flow we will have

$$\frac{v}{v_2}=\frac{\delta_2}{\delta}=\left(\frac{p_2}{p}\right)^{\frac{1}{\gamma}} \quad . \quad . \quad . \quad (13)$$

where v_2, δ_2, and p_2 are for velocity, density and pressure at the exit from the pipe considered, while v, δ, and p are for any other point in the pipe. The value of γ for air, and gases nearly perfect, is, according to best authority, $=1.408$.

By (13), (12) becomes

$$\frac{v_2^2}{2g}\left(\frac{p_2}{p}\right)^{\frac{2}{\gamma}}\frac{fs}{a}dl=\left(\frac{p_2}{p}\right)^{\frac{1}{\gamma}}\frac{dp}{\delta_2}$$

or

$$\frac{v_2^2}{2g}\cdot\frac{fs}{a}\cdot dl=\frac{p^{\frac{1}{\gamma}}dp}{\delta_2 p_2^{\frac{1}{\gamma}}}$$

which, for limits o and l and for P_2 and P becomes

$$\frac{v_2^2}{2g}\frac{fs}{a}l=\frac{\gamma}{\gamma+1}\cdot\frac{p_2}{\delta_2}\left\{\left(\frac{p}{p_2}\right)^{\frac{\gamma+1}{\gamma}}-1\right\} \quad . \quad (14)$$

the desired formula in which v_2 is the velocity at the outflowing end of pipe, and p the pressure of the gas at the inflowing end. After integration p, v, and δ, are for quantities just within the orifice of entry.

The fall of pressure from p to p_2 is due to the fluid friction in the pipe. If the pipe is comparatively short, the resistance at the orifice of entry may be too great to overlook. That is, the energy of motion required to give the gas the velocity v, may be as great, or even greater for a short pipe, than the frictional resistance. This resistance at entry is to be treated as a resistance to efflux through an orifice. Formula (3) will not apply here exactly, because now the density is variable. But (13) enables us to express the density as a function of p, thus

$$\frac{\delta_1}{\delta}=\left(\frac{p_1}{p}\right)^{\frac{1}{\gamma}} \quad . \quad . \quad . \quad . \quad (15)$$

where δ_1 and p_1 are for density and pressure in the reservoir, while before integration δ and p are for any point before entrance to pipe is fairly gained. Hence, making $p_1-p_2=dp$, eq. (3) may be put under the following form:

$$\frac{v^2}{2gu^2}=\int_p^{p_1}\frac{dp}{\delta}=\frac{p_1^{\frac{1}{\gamma}}}{\delta_1}\int_p^{p_1}\frac{dp}{p^{\frac{1}{\gamma}}}=\frac{\gamma}{\gamma-1}\frac{p_1}{\delta_1}\left\{1-\left(\frac{p}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\} \quad . \quad . \quad . \quad (16)$$

But after integration p, v and δ should be considered as in (14) for quantities just inside the entrance to the pipe. If v is found in terms of v_2 it might be used in connection with eq. (14). By aid of (13), we may write

$$\frac{v^2}{2gu^2}=\frac{v_2^2}{2gu^2}\cdot\left(\frac{p^2}{p}\right)^{\frac{2}{\gamma}}=\frac{\gamma}{\gamma-1}\frac{p_1}{\delta_1}\left\{1-\left(\frac{p}{p_2}\right)^{\frac{\gamma-1}{\gamma}}\right\} \quad . \quad . \quad . \quad . \quad (17)$$

In calculating the velocity v_2, by aid of eqs. (14) and (17), p will always be an unknown quantity, and unfortunately it cannot be eliminated so as to give an equation which is resolvable with reference to v_2. Therefore to find the whole resistance, viz., that due to orifice of entry, and to fluid friction in the pipe, it will be necessary to make a series of trials till we find such a value of p as

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will give the same value to v_2 in the two equations. That will be the desired value of the velocity of exit from the pipe, all resistances being considered.

In practice these equations for strictly adiabatic flow cannot be applied to very long pipes, because the flowing gases will acquire same measure of heat. Hence, as the resistance at the orifice of entry becomes greater in comparison with the frictional resistance as the pipe is shortened, it appears that when (14) is to be employed (17) should be also.

III. Let the pipe be considered as so long that an appreciable amount of heat is transferred to the gas while in transit through it, and yet not sufficient to make the flow isothermal. Then some modified value of γ might be used, as lying between 1.408 and 1.

But it may be more convenient to express the temperature as it varies along the length of the pipe as a function of l, or, taking τ for the absolute temperature,

$$\tau = F(l).$$

In this case, instead of eq. (13), we should write

$$\frac{v}{v_2} = \frac{\delta_2}{\delta} = \frac{P_2}{P}\frac{\tau}{\tau_2} = \frac{P_2}{P}\frac{F(l)}{\tau_2} \quad . \quad . \quad . \quad (19)$$

and hence we should have, instead of the equation next following (13), the following, viz:

$$\frac{v_2^2}{2g}\frac{fs}{a}\left(\frac{p_2}{p}\frac{F(l)}{\tau_2}\right)^2 dl = \frac{p_2}{p}\frac{dp}{\delta_2}$$

or

$$\frac{v_2^2}{2g}\frac{fs}{a}\left(\frac{F(l)}{\tau_2}\right)^2 dl = \frac{pdp}{p_2\delta_2} \quad . \quad . \quad . \quad (20)$$

an expression which is integrable when the form of $F(l)$ is known.

As an example suppose the temperature increases uniformly with the distance along the pipe from the exit up. Then, for τ_2 at exit,

$$\tau = (\tau_2 + ml) = F(l)$$

l being here variable as representing various lengths of the pipe. If l' is the whole length of pipe, and if τ_1 is the temperature at the entrance to pipe, we have

$$\tau = \tau_2 + \frac{\tau_1 - \tau_2}{l'}l$$

Hence (20) becomes

$$\frac{v_2^2}{2g}\cdot\frac{fs}{a}\left(l + \frac{ml^2}{\tau_2} + \frac{m^2l^3}{3\tau_2^2}\right) = \frac{p_1^2 - p_2^2}{2\delta_2 p_2} \quad . \quad . \quad (21)$$

But when the flow is strictly isothermal we have $\gamma = 1$ in eq. (14), or $m = o$ in eq. (21), all of which reduce to the eq.

$$\frac{v_2^2}{2g}\frac{fs}{a}l = \frac{p_1^2 - p_2^2}{2\delta_2 p_2} \quad . \quad . \quad . \quad . \quad (22)$$

Should it be desired to take into account the resistance of the orifice of entry in calculations for flow through pipes by any of the latter formulas, it may be done by use of eq. (3) or (17), as whether the fall of pressure is slight or considerable at the entry. In cases where (22) is applicable, however, it will scarcely be found necessary to consider the resistance at entry, because then the pipe will be relatively very long, making that resistance comparatively inappreciable. Eq. (22), indeed, is applicable to the case of conveying compressed air into tunnels as at Hoosac, Mont Cenis, St. Gothard, &c., or as proposed by H. H. Day, in a scheme for compressing air at Niagara Falls, to be used at Buffalo, Rochester, &c. For such extraordinary lengths the resistance at entry would vanish. The flow could then be regarded as strictly isothermal, provided the pipes were at constant temperature throughout, a condition nearly realized by burying the entire line of pipe. Formula (27) has been employed in my lectures to classes for the past 8 or 9 years.

FORMULAS FOR PRACTICE.

In the preceding the leading object has been to state the true relation between the quantities treated. As regards II and III, more convenient forms for application to practice will be considered.

First, we notice that in the use of such quantities as before us, frequent reference to tables of physical constants, &c., is necessary, and these are usually given for the temperature of melting ice. Hence:

Let p_0, δ_0, and τ_0 represent the specific pressure, specific density and absolute temperature for the temperature of melting ice. $\tau_0 = 493.°2$ Fahr.

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p_1, δ_1, and τ_1 the same for the gas in the reservoir at the point of departure in the flow.

p, δ, and τ the same just inside the orifice of entry.

p_2, δ_2, and τ_2 the same at the instant of exit.

v, and v_2, the velocity of the stream of gas at the entrance and exit.

a, s, l, sectional area, perimeter of section and length of flowing stream.

The term *specific pressure*, is taken to mean the pressure in units per unit of surface, as lbs. per square ft. *Specific density* is the weight in units per unit of volume, as lbs. per cubic ft.

For gases sensibly perfect, like air, illuminating gas, &c., we have the well-known relation

$$\frac{p_0}{\delta_0\tau_0}=\frac{p_1}{\delta_1\tau_1}=\frac{p_2}{\delta_2\tau_2}=\frac{p}{\delta\tau} \quad . \quad . \quad . \quad (23)$$

$= 53.15$, air; or $= 88.$ illuminating gas; for lb. ft. F. units, true for a given gas under all circumstances, whether expanding adiabatically, or in any other manner. But for many cases the three quantities p, δ and τ vary, as, for instance, in the adiabatic condition.

In eq. (14) the density δ_2 is unknown, but as the entire flow is supposed adiabatic, quantities in the reservoir are connected with those at other points according to (13). Hence

$$d_2=d_1\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}}=\frac{\delta_0\tau_0}{p_0}\frac{p_1}{\tau_1}\left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}} \quad . \quad . \quad . \quad (24)$$

δ_1 and p_1 being quantities in the reservoir.

The flow of weight, or weight of gas discharged, is always

$$av\delta=av_1\delta_1=av_2\delta_2=w \quad . \quad . \quad . \quad (25)$$

so that the weight can be found for the adiabatic flow, by use of (14), (17), (24), and (25). When the resistance of the orifice of entry is neglected, (17) is an necessary, and p, in (14), becomes p_1.

The second members of (21) and (22) may be put in the following form:

$$\frac{p_1^2-p_2^2}{2\delta_2 p_2}=\frac{p_0}{\delta_0\tau_0}\cdot\frac{\tau_2}{2}\frac{(p_1^2-p_2^2)}{p_2^2}=$$

$$\frac{p_0}{\delta_0\tau_0}\cdot\frac{\tau_2}{2}\left\{\left(\frac{p_1}{p_2}\right)^2-1\right\}=$$

$$\frac{p_0}{\delta_0\tau_0}\tau_2\frac{(p_1-p_2)}{p_2^2}\frac{(p_1+p_2)}{2}=$$

$$\frac{p_0}{\delta_0\tau_0}\tau_2 p_m\frac{p_1-p_2}{p_2^2} \quad . \quad . \quad . \quad (26)$$

where p_m = the arithmetical mean of the pressures p_1 and p_2.

For small differences of pressure p_1 and p_2, we have $p_m=p_2$ nearly, and (26) becomes

$$\frac{p_0}{\delta_0\tau_0}\tau_2\frac{p_1-p_2}{p_2} \text{ nearly.}$$

For air the equation (22) for isothermal flow through cylindrical pipes, becomes

$$v_2^2=284943\cdot\frac{r}{l}\tau_2 p_m\frac{p_1-p_2}{p_2^2} \quad . \quad . \quad . \quad (27)$$

r being the radius of the pipe, and the coefficient of friction being taken at

$$f=.006.$$

This equation (27) has been compared with the results of experiment as indicated in the accompanying table, the column of calculated velocities at exit having been obtained by aid of this formula. The comparisons indicate that the coefficient of friction is in some cases less in value than the .006 assumed, notably for the St. Gothard experiments, for which .004 would have given results agreeing more closely. But it is difficult to discover a law relating f with r or v, or both; which will reconcile the discrepancies shown in the table. For instance, compare the Italian experiments with the St. Gothard, for velocities of 15 to 20 ft. and diameter of pipe 7.87. Like velocities and diameters being found in both, it appears that f, stated in terms of v and r, would be the same for both and could not be otherwise. Hence f cannot be stated in terms of v and r alone, so as to satisfy all the experiments.

If f be taken as a function of p, so as to reconcile the two cases above considered, the same will be wrong for making the results of experiment of Henson and calculation agree. The experiments of Henson were made with lead pipe.

If we assume that the St. Gothard experiments are more trustworthy than the others, this would argue a smaller value of f. But from these experiments, all considered, probably no better value of $f=.005$ could be assumed.

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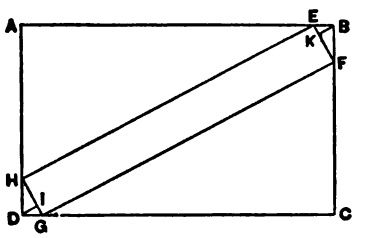
TABLE OF VELOCITIES OF COMPRESSED AIR AT THE EXIT FROM LONG PIPES. OBSERVED AND CALCULATED

Experiments.	Absolute. P_1	Absolute. P_1-P_2	d	l	τ_2	f	Velocity u_2. Calc'd	Velocity u_2. Obs'd	Diff.
	lbs.	lbs.	inches.	ft.	Fahr.				
From experiments made by order of the Italian government, preliminary to use of compressed air in the Mont Cenis Tunnel.	90.	.117	8.937	3281.	520.	.006	3.12	3.28	− .16
	—	.516	—	—	—	—	6.58	6.56	+ .02
	—	1.218	—	—	—	—	10.18	9.84	+ .34
	—	2.125	—	—	—	—	13.54	13.12	+ .42
	—	3.289	—	—	—	—	17.01	16.40	+ .61
	—	4.586	—	—	—	—	20.29	19.68	+ .61
	90.	.062	7.875	3281.	520.	.006	3.22	3.28	− .06
	—	.258	—	—	—	—	6.55	6.56	− .01
	—	.609	—	—	—	—	10.12	9.84	+ .28
	—	1.062	—	—	—	—	13.41	13.12	+ .29
	—	1.656	—	—	—	—	16.64	16.40	+ .24
	—	2.304	—	—	—	—	19.96	19.68	+ .28
	90.	.039	13.75	3281.	520	.006	3.37	3.28	+ .09
	—	.156	—	—	—	—	6.74	6.56	+ .18
	—	.351	—	—	—	—	10.14	9.84	+ .30
	—	.609	—	—	—	—	13.23	13.12	+ .11
	—	.945	—	—	—	—	16.71	16.40	+ .31
	—	1.320	—	—	—	—	19.80	19.68	+ .12
Experiments of Wm. S. Henson, at Bloomingdale, N. J., for Mr. H. H. Day. Vol. 4, p. 205.	37.00	12.0	1.25	5280.	520	.006	29.50	29.40	+ .10
	43.00	8.	—	—	—	—	19.30	20.00	− .70
	50.25	5.25	—	—	—	—	13.27	15.10	−1.83
	58.25	3.25	—	—	—	—	9.43	11.75	−2.32
	66.75	1.75	—	—	—	—	6.31	9.60	−3.29
Experiments at St. Gothard Tunnel. Vol. 24, p. 96.	82.32	5.29	7.87	15092.	531.	.006	15.32	19.99	−4.67
	63.94	3.23	—	—	—	—	13.42	16.73	−3.31
	56.45	2.79	—	—	—	—	13.29	15.97	−2.68
	77.03	3.53	5.90	1719.	541.	.006	33.04	38.05	−5.01
	60.71	1.03	—	—	—	—	19.38	30.81	−11.43
	53.65	1.54	—	—	—	—	25.53	29.76	−4.23

PRACTICAL FORMULAS FOR ANGLE BLOCKS AND BRACES OF BRIDGES.

By P. H. PHILBRICK, M. S., C. E., Professor of Engineering, State University of Iowa.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.



Let ABCD represent a panel. AD=D, AB=l

EH=L=length of brace.
EF=d=depth " "
BF=y= " " block.
BE=x=width " "
BK=h=height " "

We have $x^2+y^2=d^2$ . . . . (1)

and

$$\frac{BE}{BF}=\frac{CF}{CG};\text{ or }\frac{x}{y}=\frac{D-y}{l-x} \quad . \; . \; . \; (2)$$

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The exact values of x and y can be found from (1) and (2), only by solving an equation of the fourth degree.

A very simple and almost exact solution is, however, easily effected as follows:

Substitute

$$a=\frac{d\mathrm{D}}{\sqrt{\mathrm{D}^2+l^2}}\ldots(3);\text{ and }b=\frac{dl}{\sqrt{\mathrm{D}^2+l^2}}\ldots(4)$$

for x and y in the second member of (2), which equation then becomes

$$\frac{x}{y}=\frac{\mathrm{D}-b}{l-a}\quad\ldots\quad(5)$$

Now (1) and (5) give:

$$x=\frac{d(\mathrm{D}-b)}{\sqrt{(\mathrm{D}-b)^2+(l-a)^2}}\quad\ldots\quad(6)$$

$$\text{and }y=\frac{d(l-a)}{\sqrt{(\mathrm{D}-b)^2+(l-a)^2}}\quad\ldots\quad(7)$$

$$\text{Then }\mathrm{L}=\sqrt{(\mathrm{D}-y)^2+(l-x)^2}\quad\ldots\quad(8)$$

$$\text{Or }\mathrm{L}=\sqrt{\mathrm{D}^2+l^2}-\frac{2xy}{d}\text{ almost exactly;}\quad(9)$$

$$\text{or }\mathrm{L}=\sqrt{\mathrm{D}^2+l^2}-\frac{2ab}{d}\text{ very nearly.}\quad(10)$$

Let us compare these with the true results.

Let $d=1$, $\mathrm{D}=10$ and $l=15$.

Eq. (3) gives $a=.557$;
Eq. (4) gives $b=.831$
" (6) " $x=.5354$
Eq. (7) " $y=.8444$
" (8) " $\mathrm{L}=17.1187$
" (9) " $\mathrm{L}=17.1183$
" (10) " $\mathrm{L}=17.1148$

a and b are special values of x and y found from (1) and (2) by interchanging x and y in the second member of (2), or by omitting them from that member.

Supposing $y>x$ then is $l>\mathrm{D}$;

$$\text{and }\frac{a}{b}=\frac{\mathrm{D}}{l}>\frac{x}{y}=\frac{\mathrm{D}-y}{l-x};$$

and since $a^2+b^2=x^2+y^2$; $x<a$ and $y<b$.

Let $b=y-e$; then by virtue of the preceding equation, and since e is small,

$$a=x+e\frac{y}{x}\text{ very nearly.}$$

Hence b is less than, and also nearer the true value of y than a is to the true value of x. We therefore compute y first.

Also from the above we have $ab>xy$,

$$\text{therefore }\frac{ab}{d}>\frac{xy}{d}=\mathrm{BK}.$$

Now eliminating x from (1) and (2) I find:

$$y^4-10y^3+80.25y^2+5y-56=0.$$

By Horner's method (.831 being an approximate root of the above equation) I find $y=.845$. Then $x=.535$, and $\mathrm{L}=17.1187$.

The errors pertaining to the easy solution given above, decrease as $\frac{d}{\mathrm{D}}$ or $\frac{d}{l}$ decreases, or as $\frac{\mathrm{D}}{l}$ approaches unity. Still the errors are almost inappreciable, and are of no practical significance, even in the above very unfavorable case.

When the length only is wanted, eq. (10) is most convenient and is sufficiently exact.

It is easy to see that:

$\mathrm{BD}=\mathrm{EH}+2\mathrm{BK}+$ a small quantity, say e', and that $\frac{2ab}{d}=2\mathrm{BK}+$ a small quantity, say e'', $\therefore\ \mathrm{BD}-\frac{2ab}{d}=\mathrm{EH}+(e'-e'')$; which shows that the error involved in eq. (10) is the difference of two small quantities.

THE SOCIETY OF CIVIL ENGINEERS OF PARIS AND FRENCH PORTS.—The tonnage of the following ports during the year 1879 was given in a paper read before this society by M. Hersent: Of Antwerp it was 5,614,243 tons; Dunkerque, 726,401; Le Havre, 1,888,099; Rouen, 582,951; Bordeaux, 871,930; Marseilles, 2,591,052; Genes, 2,068,973. He also called special attention to the value of the docks projected under M. Freycinet at the port of Dunkerque. M. A. Pyotte-Beyaert, of that port, worked hard many years in the endeavor to get the necessary dock and harbor improvements carried out to give back to Dunkerque the important position it once held among the ports of France. As long ago as 1868 he caused fully matured plans and estimates to be lithographed and largely circulated in the endeavor to improve the port.

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ON SOME ELECTRO-MAGNETIC ROTATIONS OF BAR MAGNETS AND CONDUCTING WIRES ON THEIR AXES.

By G. GORE, F.R.S.

Proceedings of the Royal Society.

In all the published forms of Ampère's experiment of the electro-magnetic rotation of a vertical bar magnet or conducting wire upon its axis by Ampère, Faraday, Sturgeon, and others, the magnet or wire has either been immersed a large portion of its depth in mercury, or its middle part has been connected by a wire with a surrounding annular channel filled with mercury, and the electric current passed into or out of the magnet or wire by means of that liquid, and the mercury has formed an essential part of the arrangement.

In different treatises on electro-magnetism, either no explanation or different ones are given of the cause of the rotation of the magnet or wire. The most usual cause assigned is the action of the portion of current in the mercury and the fixed conductor immersed in it upon the current in the rotating wire or magnet; and the correctness of this explanation is proved by the simultaneous movement of the mercury in the opposite direction.

De la Rive, in his Treatise on Electricity (English edition, 1853, vol. i., page 259) very correctly remarks: "It must not be supposed that the phenomenon of rotation is due, as has been erroneously stated, to the action upon the magnet of the portions of the current that traverse it, or that traverse the conducting wires attached to the magnet and move with it. In fact, how could a solid system be set in motion by a force emanating from a portion of the very system itself, and connected with it in an indissoluble manner? The action can only arise from a part of the current which is independent of the system that moves. This part is the portion of the circuit which is not connected with the magnet that is set in rotation, and which consequently is situated independent of the system in motion. This kind of action has been calculated by M. Ampère in a perfectly rigorous manner."

Although the action of the portion of the current in the mercury and the fixed conductor in contact with it upon the movable current in the rotating wire or magnet is a cause of the movement, there are other circumstances which co-operate to produce the rotation, and which are themselves capable, without assistance, of producing it. Wiedemann and myself have shown that an electric current passing from one end to the other of a magnetized iron rod or wire having *dissimilar* poles at its two extremities produces torsion of the wire (the two ends of the wire moving of course in opposite directions), and that reversing the direction either of the current or of the magnetic polarity, reverses the direction of the twist. In all published cases of rotation of bar magnets on their axis by the influence of electric currents, the two ends of the magnet have had *dissimilar* poles. By meditating upon certain facts connected with this subject, I concluded that, by passing a current from one end to the other of a magnetized rod or wire having *similar* poles at its two ends, the magnet would probably rotate; and experiment has demonstrated that conclusion.

Upon a thin wooden tube 15 centims. long and 7 millims. bore I wound a cotton-covered copper wire 1.7 millim. diameter from one end of the tube to the middle, then reversed the direction of winding and continued to the other end and back to the middle, again reversed and coiled to the first end of the tube; by which arrangement the passage of a current through the coils produced two similar poles at the ends of the tube, and two others of the opposite kind at the middle.

The tube being now fixed in a vertical position, a straight iron wire 15 centims. long and 1.8 millim. diameter, pointed at its lower end and surmounted by a brass mercury cup 5 millims. diameter, containing a drop of mercury, was sup-

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ported entirely within the tube and free to rotate, by a similar cup (surmounting a fixed vertical brass rod) at the lower end of the tube, the upper end of the axial wire being kept in position by a vertical brass rod fixed above the coil, and terminated at its lower end by a sharp point of platinum in the mercury cup.

A current from 6 one-pint Grove's elements arranged as 3 being now passed through the coil, brass rods, and axial wire, the latter rotated rapidly.

With a downward current through the axial wire, and north poles * at the ends of the tube, the upper end of the wire rotated in the same direction as the hands of a watch. Reversing the direction of the current either in the coil or iron rod, reversed of course the direction of motion. The rotation in this case was not due to obliquity of coil-current, because that was neutralized by the second layer of coils; nor to portions of transverse currents proceeding to or from the brass rods, because each of those portions was 10 centims. distant from the ends of the axial wire; nor was it due to the portions of current entering or leaving the coil, because they entered and left at the same part and in parallel directions, and thus neutralized each other's effect. A copper wire substituted for the iron one would not rotate, probably because copper is so little capable of acquiring longitudinal magnetism.

To ascertain if the rotation was merely due to an action of the current in the coil upon either the axial current or longitudinal magnetism of the iron, or whether the coil current simply performed the function of longitudinally magnetizing the axial wire, I took an iron wire 23 centims. long and 2.7 millims. diameter, sharp pointed at its lower end, soldered to its upper end a double wire of cotton-covered copper, each wire being 1.7 millim. diameter, coiled the double wire upon the axial rod in two layers (so as to enable two *similar* poles to be formed at the extremities of the axis), and terminated the copper wires by a little brass mercury cup just above the top end of the vertical iron axis. By supporting this apparatus as the axial wire in the previous experiment, and passing the current, rotation occurred, showing that the chief use at least of the coil current was to impart longitudinal magnetism to the axial wire, and that the rotation was not simply due to any reaction between the coil and that wire. Reversing the direction of the current did not reverse the direction of rotation. In another experiment similar to this, I formed about 12 centims. in length of the middle part of the axial wire of copper instead of iron, and obtained similar rotation; but as copper is only slightly capable of acquiring longitudinal magnetism from a coil current surrounding it, a precisely similar apparatus having an axial wire composed entirely of that metal would not rotate.

These experiments and the following ones produce a striking effect in a lecture, because the rotation appears to be produced without reaction of the moving part of the apparatus upon any external or fixed body.

To determine whether the longitudinal element of the coil current obtained by obliquity of winding of the wire might be substituted for the longitudinal current through the magnet, I took an iron wire 13 centims. long and 1.7 millim. diameter, sharp-pointed at its lower end, soldered near to that end one extremity of a cotton covered copper wire 1.7 millim. in diameter, coiled the latter in one direction to the middle part of the iron wire, then reversed the direction of winding and coiled to the other end of the iron, and terminated the coil by a little brass cup just above the upper end of the iron wire as before. By supporting this apparatus as in the previous experiments, and passing the current, rapid rotation took place, proving that a longitudinal current in the iron itself was not necessary.

To ascertain whether the longitudinal element of the current was essential to the motion, I constructed a similar apparatus to the last, but instead of attaching the upper end of the coil wire direct to the brass cup, I continued the copper wire vertically downwards to the bottom of the coil, to neutralize the effect of obliquity of winding; then carried it outwards and upwards in the form of a large rectangle 5 centims. distant from the coil and on to the mercury cup. On

* By a North pole I mean that which points to the South, and by a South one that which seeks the North.

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passing the current rotation occurred freely, showing that the longitudinal current was not essential to the motion. This experiment, and that described in paragraph 4, appears to prove that the rotation is not an effect of any obliquity or spiral arrangement of the axis of the magnetized iron molecules with regard to the axis of the wire, produced by the combined action of the transverse and longitudinal elements of the current in the coil, because the latter element was neutralized, but that it is an effect of the tangential poleless magnetism in the fixed wires above and below upon the longitudinal magnetism of the movable iron axis and its coil.

As an electric solenoid, however, possesses in some degree many of the properties of a magnet, its longitudinal magnetism, though feeble, must have operated in some of the previous experiments; and I therefore now tried to obtain rotation of one by the action of vertical currents. Upon a very thin wooden tube 15 centims. long and 12 millims. external diameter, I coiled a single stout cotton-covered copper wire from one end to the other, reversing the direction of winding at the middle of the tube, and surmounting the upper end of the wire by a small brass cup containing mercury. The lower end of the wire was sharply pointed, and the coil was supported as in the previous experiment. By passing the current from 6 one-pint Grove's elements arranged as 3, faint signs of rotation were observed.

In each of these cases of rotation an upward vertical current entering a lower south pole or leaving an upper one caused the upper end of the rod to rotate in the direction of the hands of a watch, and a downward current entering or leaving a north pole also produced that direction of motion, and reversing the poles in either case reversed the effect.

In each of these instances of rotation, without the aid of a current near the middle of the magnet, the coil being so constructed that the current in it could not be reversed without reversing that in the fixed conductors near it, reversing the direction of the current did not reverse that of the rotation, because the two acting influences were reversed together; and therefore each apparatus had its own direction of rotation, either right-handed or left-handed (↻)*, according to the direction in which its coils were wound. It follows from this that a current, the direction of which is alternately reversed, will drive the apparatus quite as well as one in one uniform direction.

As the rotation was apparently due to the influence of the tangential poleless magnetism of the portions of vertical current in the fixed conductors upon the longitudinal magnetism of the vertical iron axis and its coils, I now endeavored to increase the effect. For this purpose I substituted for the upper brass rod a fixed coil consisting of one layer of copper wire upon an iron wire axis, but having dissimilar poles at its ends and no poles at its middle part, and placed between it and the lower brass rod a similar right-handed one to that described in paragraph 6 and free to rotate. The opposed poles of the fixed and movable coils were of opposite kinds, *i. e.* north and south. On passing a current from a Noe's thermopile of 96 elements † connected as 24, rapid rotation in a right-handed direction occurred. I now substituted for the lower brass rod another fixed coil, similar to the upper one, but of an opposite direction of polarity, and passed the current again; still more rapid rotation in the same direction took place, and the effect was very striking. In this latter instance two south poles free to move were opposed to two fixed north poles, and in each instance the current was passed upwards. In the second experiment also the longitudinal magnetic influence of each opposed iron axis and coil acted upon the tangential magnetism of the longitudinal element of the end of the copper coil current opposed to it, and thus both the longitudinal and the tangential magnetism of each of the four opposed ends co-operated to produce a most effective result.

With a thicker axial wire in the moving coil the rotation was not so rapid; and with an axial wire of the usual thickness, but a double layer of copper wire coils, and the current passing through the axial wire, the rapidity of rotation was not much altered, probably because the

* By a "right-handed" coil, I mean one the upper end of which rotates in the same direction as the hands of a watch.

† I have found this apparatus very convenient for such experiments.

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increased weight and friction counteracted the effect of the increased magnetism. By substituting for the right-handed movable coil with south poles at its extremities, in these experiments, a left-handed one with north poles at its ends opposed to north poles of the fixed ones, and passing the current, no rotation occurred: in this case the longitudinal element of the current in the movable coil, acting upon the longitudinal magnetism of the fixed iron axis and its coil, tended to produce rotation in one direction, and the longitudinal magnetism of the movable axis and its coil, acting upon the longitudinal element of the current in the fixed coil, tended to produce rotation in the opposite direction.

I now substituted for the movable coil a vertical wire of iron 13 centims. long and 1.7 millim. diameter, surmounted by a small brass mercury cup, passed the current from the thermopile, and obtained rotation, but less rapid than before, probably because of the less degree of longitudinal magnetism; but by enclosing this wire in the axis of a fixed coil which produced appropriate and similar coils at its two ends, as in paragraph 4, and repeating the experiment, very great velocity of rotation was obtained. Rotation of a somewhat thicker wire of nickel was also obtained, both with and without the aid of the current in the middle fixed coil. I also tried, without the aid of the middle fixed coil and with it, a copper wire of similar dimensions to the iron one, and obtained rotation freely; in this case the motion was probably nearly wholly due to the action of the longitudinal magnetism of the adjacent ends of the fixed axial wires, and their coils upon the tangential magnetism produced in the movable copper wire by the axial current. Each of these rotations agreed in direction with those of the movable coil.

I also obtained rotation of the iron wire whilst the wire was in a horizontal position, its ends resting in hollows in the ends of the iron axis of the two fixed coils, and the ends of those axis and of the movable wire lying upon the surface of pools of mercury in small watch glasses. The movable iron wire was enclosed in the axis of a thin iron tube within a fixed coil, having appropriate and similar poles at its ends. The current from the thermopile produced very rapid rotation. This result proves that the rotations are not due to terrestrial magnetic influence.

As the directions of magnetic polarity, electric current, and rotation agree with those in the different forms of Ampère's experiment, and as in most, if not all, of the previously known cases of rotation of a bar magnet or conducting wire on its axis an electric current passes through the end of the bar or wire, it is evident that those rotations were due, not only to the portions of current in the mercury and fixed conductors connected with it near the middle of the magnet or wire, but also to the influence of the currents in the fixed conductors near the ends of the magnet or wire.

[NOTE.—It having been suggested by Professors Maxwell and Stokes that the rotation in the foregoing experiments was due to the influence of the portions of current in the cups of mercury, or in the fixed conductors near the ends of the movable wire or magnet upon the movable magnet, I diminished the internal diameter, both of the upper and lower cups, from 4 millims. to 1.75 millim., and arranged the following apparatus and experiment.

The fixed upper wire was of brass, 2.5 millims. diameter and 60 millims. long; it had no coil upon it, and was used as a conductor only; its lower end terminated in a fine point of a steel needle projecting 6 millims. The lower fixed wire (also used as a conductor only) was of platinum, to resist the action of the mercury; it was 2.3 millims. diameter and 75 millims. long, with a cavity in its upper end 3.5 millims. deep and 1.75 millim. diameter, and containing a thin plate of ruby in its lower part, with a minute hole in the center for the needle point to rotate in. The movable wire was 2.5 millims. diameter and 125 millims. long, its upper half being composed of soft iron and its lower half of brass; its lower end terminated in a needle point like that of the upper fixed wire, and its upper end had a cavity and perforated ruby plate like that in the lower fixed wire. A voltaic coil 60 millims. long and 7 millims. internal diameter, composed of four layers of cotton covered with stout copper wire, was used to magnetize the iron half of the movable wire, and

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fixed by means of a separate support in a proper vertical position beforehand, so as to enclose in its axis the iron wire portion only. The little cups were also each half filled with a minute globule of mercury before putting the movable wire into its place.

After adjusting the wire so as to make rotation easy, a current from 6 Grove's elements of one-pint capacity arranged as a series of 6, also as a double series of 3, was passed through the coil and vertical wires, and the direction of the portion of the current in the coil alone, also in the vertical wires alone, was varied; but notwithstanding that plenty of current passed, no signs of rotation could be detected. These results, therefore, strongly support the opinion that the rotation in the experiments was due to the action of the portions of the current in the cups of mercury.]

ON THE ACTION OF COKE SLAG ON FIREPROOF MATERIALS.

By Dr. B. KOSMANN.

From "Abstracts" of the Institution of Civil Engineers.

THESE experiments were undertaken with the object of ascertaining what relation exists between the composition of the fused slag resulting from the combustion of coke at a high temperature and the deterioration of the fire bricks subjected to the action of such slag. At the same time and for the purpose of comparison, analyses were made of the ash produced by the same coke when burned at a lower temperature. It has been usual, in investigating the action of the slag produced by fuel upon fire-proof materials, to analyze the ash of the fuel before it has undergone fusion. That such a practice must, in many cases, lead to erroneous conclusions may be seen from the examples given below. The experiments were conducted in regenerator furnaces for heating gas retorts. In these furnaces the fire bricks, especially in the neighborhood of the slits through which air is admitted, are very rapidly corroded, unless their composition is adapted to the acid or basic nature of the slag with which they are brought into contact.

The first series of experiments was made with a regenerator furnace on Müller and Eichelbrenner's system. The coke used was from the Gelsenkirch district, and contained 11.92 per cent. of ash. When produced at a temperature which did not suffice to fuse it, the composition of this ash was that given under A. B is the ash of the same coke fused at the temperature prevailing in the furnace:

	A.	B.
Silica	47.91	62.95
Alumina	30.17	25.23
Ferric oxide	12.16	—
Ferrous "	—	3.12
Manganic "	0.38	—
Manganous "	—	0.28
Lime	1.41	0.46
Magnesia	1.22	0.92
Soda	2.60	2.82
Potash	3.34	3.51
Sulphuric acid	0.82	—
Phosphoric "	—	0.55
Metallic iron	—	0.09
Ferrous sulphide	—	0.04
	100.01	99.97

The fused slag formed a dark glass of the specific gravity 2.52, and enclosing globules of metallic iron. At the higher temperature, therefore, both iron and manganese had been reduced to lower stages of oxidation, part of the former even to the metallic state. The sulphates of lime and magnesia had been either volatalized or removed by mechanical means, and the potash and soda remained in the slag. Although the ash is of a decidedly basic character before fusion, yet the slag produced from it is acid. In this case the use of fire bricks with an excess of acid constituents was indicated. Those used contained 89 per cent. of silica, and resisted the action of the fused slag remarkably well.

In the second series of experiments

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the regenerator furnace was constructed on Liegel's system. The coke was made from a mixture of ⅔ Nettlesworth and ⅓ Leverson coal. The proportion of ash in the coke was 9.24 per cent.; its analysis is given in the following table under A. After the furnace had been working for three days the sample B was taken. It was but partially fused, the action of the furnace being imperfect, owing to the air slit being too large. When this had been reduced in size the slag was easily fused, and had the composition C:

	A.	B.	C.
Silica	43.84	51.80	34.55
Titanic acid	0.86		3.40
Alumina	21.16	29.27	41.26
Ferric oxide	11.84	11.24	—
Ferrous "	—	—	0.43
Manganic "	0.61	1 26	—
Manganous "	—	—	0.25
Lime	10.53	6.85	15.14
Magnesia	0.41	1.12	0.57
Soda	0.86	0.33	0.06
Potash	1.88	0.70	0.67
Sulphuric acid.	7.17	—	—
Phosphoric " .	0.61	—	—
Sulphur	—	—	0.19
Metallic iron	—	—	3.75
	99.27	102.57	100.27

The apparent excess in B is due to the oxygen of the iron and manganese compounds, part of which were present in the lower stage of oxidation. The presence of titanic acid is remarkable in these analyses. The changes which took place during the first stage of fusion (B) were not important. In the second stage (C), when completely fused, the slag became more basic in its character than the ash from which it was derived. There was a considerable reduction of metallic iron, which was found in numerous globules interspersed throughout the dark, vitreous mass. In this case also the sulphates had been volatilized. The iron globules were very impure, containing only 36 per cent. of metallic iron.

After the furnace had been in work some months the draught became defective, and, on the flues being opened, they were found lined with a ¾ inch coating of a light, porous substance, which was found on analysis to contain 72 per cent. of silica and a large proportion of sulphates. It probably owed its origin to the decomposition of the slag by steam, assisted by the action of the sulphates present. This furnace was lined with fire bricks containing as high a proportion of alumina as possible; they resisted the action of the basic slag so well that their wear was almost imperceptible.

The coal used in the third series of experiments was from Upper Silesia, and contained 3.54 per cent. of ash, of the composition given below under A:

	A.	B.
Silica	61.18	61.32
Alumina	26.07	23.79
Ferric oxide	7.32	—
Ferrous "	—	7.41
Manganous "	—	0.78
Lime	1.32	3.60
Magnesia	1.18	1.50
Soda	0.33	0.80
Potash	1.79	1.35
Loss as gas	0.47	—
	99.66	100.55

The regenerator was lined with the best Garnkirk fire bricks; but, as will be seen from the analysis B, the slag was of so acid a nature that these bricks were speedily corroded, and in a short time completely destroyed. Other bricks, containing 89 per cent. of silica, were therefore substituted, and left nothing to be desired with regard to durability. —*Journal fur Gasbeleuchtung.*

In the early future india-rubber ought not to be an expensive article. According to information concerning the plant which produces Ceara rubber, contained in the report on india-rubber by Dr. H. Trimen, of Ceylon, the plant is very hardy, and will grow in a dry, rough soil, and a moderately dry, hot atmosphere, while the Para and West India rubber plants require a rich alluvial soil, and a constantly hot-moist atmosphere. Ceara-rubber plants have been found to succeed in Ceylon, Calcutta, and Madras, but the climate of Singapore is too wet for them. It is suggested, says the *Journal of the Society of Arts*, that plantations should be formed on exhausted coffee land. The tree grows to about thirty feet or more in height, and forms a dense rounded crown. It attains a diameter of four inches or five inches in about two years, when it may be tapped.

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ON THE DISCHARGE OF WATER THROUGH SLUICES AND SIMILAR ORIFICES.

By K. R. BORNEMANN.

Foreign Abstracts of Institution of Civil Engineers.

THE first part of the paper treats of the flow of water through submerged sluices, and the author gives the results of an extensive series of observations made by himself with a view of determining the coefficients of discharge for such cases. The experimental sluices were made by placing a flat board across a parallel trough, the board resting against a strip on each side, the bottom of the opening being formed by and flush with the bottom of the trough. The height of the opening was varied by raising or lowering the sluice board, and three different widths of troughs and sluices were used. In experiments 1 to 16 the trough was 1.135 meter wide (44.7 inches), and the clear opening 1.006 meter (39.6 inches) wide; in experiments 17 to 44 the trough was 0.544 meter (21.42 inches), and the opening 0.520 meter (20.47 inches) wide; and in the final series 45 to 63 the trough measured 0.802 meter (31.75 inches) wide, and the opening 0.774 meter (30.47 inches) wide.

In the above experiments weir boards were inserted in the trough about 11 feet 4 inches below the sluice, so as to pond up the tail water sufficiently to submerge the issuing stream.

Let Q = quantity of water discharged in cubic meters per second.

a = height of opening.
b = breadth of opening.
h_1 = height of surface of head water above top edge of opening.
h_2 = height of surface of tail water above top edge of opening.
k = head due to velocity of approach of head water.
μ = coefficient of discharge.

} meters.

Then $$\mu = \frac{Q}{ab\sqrt{2g\,(h_1 - h_2 + k)}}.$$

g being the acceleration due to gravity.

The effective head $(h_1 - h_2 + k)$ varied from 21 millimeters to 231 millimeters (0.83 to 9.09 inches).

The author endeavors to find an empirical formula from which μ can be calculated so as to agree with the experiments. He tried successively eleven different formulæ, and determines the coefficients in each case from the experiments by the method of least squares. The two formulæ which give the most satisfactory results for submerged discharge are

$$\mu = \alpha + \beta \frac{\sqrt{a}}{h_2 + \frac{a}{2}};$$

$$\mu = \alpha + \beta \sqrt{\frac{a}{h_1 + \frac{a}{2}}} + \gamma \frac{1}{\left(h_2 + \frac{a}{2}\right)\sqrt{b}}.$$

With the experimental sluices he finds as the most probable values of the coefficients for the whole sixty-three observations:

For the first formula
$\alpha = 0.54138$; $\beta = 0.14965$

For the second formula
$\alpha = 0.43479$; $\beta = 0.25666$; $\gamma = 0.031212$.

The author also gives some experiments on submerged discharge communicated to him long ago by Weisbach. In these the trough was 0.363 meter (14.29 inches) wide, and the opening the same, there being no side strips. The bottom edge of the sluice was also beveled off on the tail water side. The conditions of experiments vary too much, and their number is too few to deduce reliable formulæ from them.

This part of the paper also contains a critical examination of some formulæ proposed by Linnenbrügge, and published in 1879 in the *Civilingenieur*. These formulæ the author considers unsatisfactory.

The second section of the paper deals

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in similar manner with the best extant observations on free discharge from sluices; the data used being the experiments by Weisbach, by Boileau, and by Lesbros.

The empirical formulæ for the coefficient of discharge are as follows: the head to the *center* of the opening being h, and the clear height and width a and b as before, all in meters.

For sluices built across a trough 0.9 meter (35.4 inches) wide, the opening reaching the whole width, and the bottom being flush, along the top of opening only, for heads to 0.580 meter (22.8 inches)

$$\mu = 0.5805 - 0.01898\sqrt{\frac{a}{h}} + 0.00144\left(\frac{1}{a}\right).$$

For sluices 0.364 meter (14.33 inches) wide, and of a similar construction, but with the lower edge of the sluice rounded, and with low heads

$$\mu = 0.8624 - 0.2194\sqrt{\frac{a}{h}} + 0.00219\left(\frac{1}{a}\right).$$

For sluices 0.6 meter (23.62 inches) wide, in which the bottom and sides of the opening are distant from the sides of the trough, so that contraction takes place all round, for heads to 1.800 meter (5 feet 11 inches)

$$\mu = 0.5732 + 0.01355\sqrt{\frac{a}{h}} + 0.02109\sqrt{\frac{1}{a}}.$$

For sluices similar to the last, but with guide strips all round the opening, 5 centimeters (2 inches) from the edge, for heads to 1.800 meter

$$\mu = 0.4488 + 0.06293\sqrt{\frac{a}{h}} + 0.5122\frac{b}{2(a+b)}.$$

The author remarks upon the great variation which the above coefficients show, and considers that till a much greater number of systematic experiments have been made, the use of sluices for gauging water is only permissible in those cases in which the conditions and dimensions are within the limits of those of the present experiments.

The third section of the paper discusses the experiments by Poncelet and Lesbros on the discharge through orifices in thin plates. Retaining the notation as in the second section, the author finds:

The rectangular orifices 0.200 meter (7.87 inches) wide, and with contraction all round; for heads up to 1.800 meter (5 feet 11 inches)

$$\mu = 0.5951 + 0.01360\sqrt{\frac{a}{h}} + 0.0008844\left(\frac{1}{a}\right).$$

And for similar orifices 0.020 meter (0.787 inch) wide

$$\mu = 0.6262 + 0.003291\sqrt{\frac{a}{h}} + 0.0002063\left(\frac{1}{a}\right).$$

For openings 0.200 meter (8 inches) wide, but without contraction along the bottom edge

$$\mu = 0.5074 + 0.02126\sqrt{\frac{a}{h}} + 0.3958\frac{b}{2(a+b)}.$$

For orifices 0.200 meter wide, with contraction along the top and bottom, but not at the sides

$$\mu = 0.6550 + 0.03611\sqrt{\frac{a}{h}} - 0.07884\left(\frac{a}{a+b}\right).$$

For orifices fitted with a trough-shaped mouthpiece in front, and contraction at the top and sides, but not at the bottom

$$\mu = 0.6945 - 0.1364\sqrt{\frac{a}{h}} + 0.005651\frac{b}{2(a+b)}.$$

For similar orifices, with contraction at the top and the bottom, but not at the sides

$$\mu = 0.6967 - 0.1033\sqrt{\frac{a}{h}} - 0.06244\frac{a}{a+b}.$$

An appendix to the paper examines the formulæ given by Weisbach and Grashoff for correcting coefficients of discharge for partial or incomplete contraction; the author finds that these all fail when used beyond the limits of the observations from which they were determined.—*Der Civilingenier.*

An English engineer recently returned home from a visit to American steel works, where enormous output is secured per converter, says: "They do it, I do not know how, but the men seem smarter, everything is ready, and the men follow each other up in their duties with rapidity and intelligence."

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AN INSTRUMENT FOR THE DETERMINATION OF LATITUDE.

By S. C. CHANDLER, Jr.

From Proceedings of the Society of Arts.

It requires a great deal of temerity to claim anything novel in the determination of time and latitude, and even more to claim an improvement in this respect. Nevertheless, I believe that the principle involved in the instrument I have devised is novel, for, after a careful investigation, I have not been able to discover any instance where it has been used in the same way.

The nearest approach to it, in previous constructions, is to be found, I believe, in the floating collameter which Captain Cater invented in 1805, for obtaining the zero point of a vertical graduated circle; but no one seems to have had the idea of floating a telescope on mercury. Thus far the astronomical transit instrument has been the universally acknowledged means for the accurate determination of time. Astronomical transits vary in size, from those which are as small as the ordinary surveyor's transit to those of eight inches aperture and ten feet focal length, and two or three thousand pounds weight. These instruments are placed in the plane of the meridian, and it is intended that, as the telescope turns in the Y's, its axis shall remain always in the plane of the meridian.

The measurement of time means merely the measurement of the angle which a point in the celestial sphere has described.

In order to determine the error of a time-piece, therefore, by means of the transit instrument moving in the plane of the meridian, it is only necessary to observe by means of this time-piece the time at which a certain star crosses the meridian, and then, knowing the time at which it should cross the meridian, we have in the difference the error of the clock.

Certain difficulties are met with, on account of the inaccuracy of the construction, and of these the following four are the principal ones, viz.;

1. Error in pivots. The axles on which the telescope turns cannot be made perfectly circular, and are not of absolutely the same size; and this deviation from the perfectly circular form, and from absolute equality in size, causes irregularity in the motion of the telescope.

2. Error in collimation. This error is due to the telescope not being perpendicular to the axis on which it turns; and causes the telescope to describe a small circle of the heavens to one side of the meridian. The correction for this is determined by observing some slowly moving star, and then, before it has crossed the field, reversing the telescope in the Y's and observing again.

3. Error in level. The deviation of the instrument, on account of the axis on which it turns not being horizontal, is ascertained by means of a level supported on the two pivots, the errors of the level itself being eliminated by reversing it.

4. The error in azimuth has to be determined by astronomical observations.

We thus have in the transit four errors to be allowed for, viz.: error in pivots, in level, in collimation, and in azimuth. In the instrument which I have devised three of these errors are eliminated, and there only remains one error, which is analogous to the error in collimation of the transit.

This instrument, made by Mr. Clacey, of this city, consists of a base of walnut with approximate leveling screws at the four corners. From the middle of this base rises a pillar of black walnut, firmly bolted to the base, and surrounded by collars of hard brass. An outside sleeve of hard brass, which turns on these collars, supports the remainder of the instrument—this sleeve being rotated in azimuth by a rack and pinion movement, and provided at its base with a graduated setting circle. On top of this sleeve is a wooden cross head which supports a wooden trough in the form of a hollow rectangle, and in this trough is placed

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mercury to a depth of one-eighth of an inch. The trough is constructed of wood instead of brass, because the mercury would attack brass. Whether it would be better to use cast iron is an open question.

In this trough, on the mercury, there floats a wooden float, also in the form of a hollow rectangle, and nearly as large as the inside of the trough, this float being held in position at the middle of the two sides by two cast iron pins which move in vertical slots in the sides of the float, and which are sufficiently loose not to interfere with its floating freely, but which serve to prevent any violent or sudden motion.

The above-mentioned float has attached to it two brass arms which support the telescope, the latter projecting through the hollows of the hollow rectangles of the float and trough.

The trough is not supported in the middle, but nearer one end, in order to allow of zenith observation; and on this account a counterpoise is attached at the other end of the trough.

The attempt has also been made to so proportion the parts as to bring the center of gravity of the floating part as near the axis of oscillation of the telescope as possible, in order to reduce oscillations due to jars, etc.

The illumination is effected by a series of reflectors, and comes from the side. The cross hairs are horizontal, and not vertical as in the transit. The reason for this will be explained later. In using the instrument the telescope is set at a certain inclination to the vertical, and, as the instrument is rotated in azimuth, the line of sight sweeps out a horizontal, small circle of the heavens, *i. e.*, a circle of which the zenith is the pole.

For the determination of the zenith, the free, upper surface of a liquid is used, and we have dispensed with the error of pivots, the error of level and the error of azimuth, and have left only what is, in a certain sense, analogous to the error of collimation in a transit instrument, the characteristic of both errors being that the telescope describes a small circle parallel but very close to the circle in which it is intended to revolve. The amount of this deviation in this instrument is not, however, determined by reversals of the telescope, as in the case of the transit, but by observation of the stars, in a similar way to that by which the azimuth error of the transit is found. As to the disturbance of the instrument by oscillations, the most violent oscillations I have been able to produce have required thirty seconds to have their effect dissipated, and after this time had elapsed the instrument is as quiescent as though it were mounted on stone.

It is, of course, specially adapted for observing equal altitudes, and can also be used to observe the transit of stars across any desired small circle having the zenith for a pole, and hence the reason why the cross hairs are horizontal instead of vertical.

All observations are influenced by refraction, but refraction operates to elevate all the stars equally at the same time. Hence, we can disregard the error of refraction in a series of observations, taken so near each other that there is no probability that the coefficient of refraction of the air has changed, and we can simply account it as part of the instrumental error; it having the same coefficient, hence, when the observations are reduced to middle time, this error is almost wholly eliminated. Next, as to the results that can be obtained by this instrument, I have not yet been able to make a great many observations, but those that I have made encourage me to believe that when as good mounting is given to it as is given to an astronomical transit, better results can be obtained with it than with the latter. I have used it very roughly, making observations from the roof of my house, which was subjected to a constant jarring from the teaming in the street below, and where the instrument was exposed to the wind.

All the observations that I have made are the following:

Showing the determination of clock correction on various dates, by combining stars in pairs, east and west, after latitude correction had been introduced. It should be noted that the instrument is of one and three-quarters inches aperture, and twenty-five inches focal length, provided with but five threads, whose intervals have, as yet, been only imperfectly determined, and that it was mounted in the open air, over a box of sand, and was entirely unprotected from the wind.

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The observations of the 5th of January were made from the middle of the roof of a four-story dwelling.

January 25, 1880.

Chronometer Correction.

1st pair	−24.93	seconds	of	time.
2d "	−25.12	"	"	"
3d "	−25.06	"	"	"
4th "	−25.08	"	"	"
5th "	−25.06	"	"	"
6th "	−25.14	"	"	"
7th "	−25.06	"	"	"
8th "	−24.99	"	"	"
9th "	−25.11	"	"	"

February 8, 1880.

1st pair	+38.06
2d "	+37.92
3d "	+38.03
4th "	+38.02
5th "	+38.14
6th "	+38.25

From Roof.

January 5, 1880.

1st pair	−6.34	seconds	of	time.
2d "	−6.13	"	"	"
3d "	−6.12	"	"	"
4th "	−6.31	"	"	"
5th "	−6.15	"	"	"
6th "	−6.62	"	"	"
7th "	−6.44	"	"	"

1880.	No. of Stars Observed.	Probable Errors.	
		Of Chron. Correction.	Single Observation.
Jan. 5.	15	±0.040	±0.156
Jan. 25.	21	±0.045	±0.206
Feb. 8.	16	±0.047	±0.183

The following were the probable errors on nights when observations were made for both latitude and time, the large probable errors being due to the use of stars near the meridian, which move very slowly in altitude:

1880.	Stars Observed.	Probable Error.	Single Observation.
		Chron. Correction.	
Jan. 31.	14	±.087	±0.323
Feb. 5.	15	±.061	±0.355

The following are the results for latitude:

1880.	Latitude.	Probable Error.
January 31....	42° 20′ 24.″95	±0.″90
February 5 ...	42° 20′ 24.″80	±0.″85
February 8....	42° 20′ 23.″25	±0.″84

The above are all the observations taken thus far, and form an exceedingly good set of results. I have not at present access to any results obtained with portable transits of the same size, with which to compare them, but do not believe that as good results can be obtained with the latter instruments. I have, however, compared my results with those of larger coast-survey transits, and mine are the best.

I have not yet determined all the constants of the instrument. I find that the wind does interfere with it somewhat when employed in the open air, and unprotected, but the deflections from this cause are but momentary, and errors due to a draught would be nearly eliminated were a greater number of cross hairs used.

Next, as to latitude. The transit instrument, when placed in the meridian, is used only for time; it can be used for the determination of latitude if placed in the prime vertical. The Coast Survey have introduced for this purpose the zenith telescope, and have obtained with it the very best results. To compare my instrument with this is a very severe test; but it will be seen that, although I have had only three evenings on which I could make observations for latitude, the results obtained are remarkably good. The claims, therefore, that I make for my instrument are the following, viz.:

1. The ability to use any part of the heavens that are not obscured by clouds. In using the transit it is often impossible to obtain observations when clouds hang in the meridian, even though there may be any amount of clear sky on either side. With my instrument we can use any region of clear sky in the heavens, as we can use any horizontal circle whatever; although the use of the same circle all the time renders the computations easier.

2. There is only one instrumental error to determine inatead of four.

3. This instrument is unaffected by errors in mounting.

4. Simplicity in use; requiring no readings of level nor reversals. In the use of the transit about one-half the time is taken up by these processes, which are unnecessary with my instrument.

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5. The construction is very cheap.

6. Combination of a time and latitude instrument in one.

7. It admits also, of the application of a delicate micrometer on an entirely new principle, as a micrometer screw carrying a weight could be mounted on the float, thus enabling us to move the center of gravity of the floating part, and to tilt the axis of the telescope. We can thus apply here the same methods that we can in the zenith telescope.

THE BEHAVIOR OF RAILWAY CARRIAGES IN PASSING CURVES.

By F. HOFFMANN.

Foreign Abstracts of the Institution of Civil Engineers.

THE author draws attention first to the case of a simple wagon with rigid wheel-base, and on each of whose axles two wheels with coned tires are immovably fixed. He gives the most general form of equation between work and resistance on a curve, and thence derives the form it takes in practical cases, viz.,

$$K=Gf\left(\frac{L}{R}+\frac{s}{R}-\frac{1-a}{1+a}-\frac{1-b}{1+b}\right) \quad \ldots (1)$$

where K is the resistance, G whole load on one axle, f coefficient of friction, L wheel base, R radius of a curve, s the width of gauge from center to center of rails, a ratio of running radius of inner to that of outer wheel on front axle, and b the same ratio for hind axle. The part $Gf\frac{L}{R}$ is due to transverse sliding, the rest to the rotation of one wheel about the other on each axle. This expression shows that the resistance is small for light load, smooth rails, narrow gauge, short wheel-base, large radius of curvature, and values of a and b near the limit $\frac{R}{R+s}$.

Of the equations

$$K=Gf\frac{L}{R} \quad \ldots (2)$$

$$K=Gf\left(\frac{L}{R}+\frac{s}{2R}\right) \quad \ldots (3)$$

$$K=Gf\left(\frac{L}{R}+\frac{s}{R}\right) \quad \ldots (4)$$

$$K=Gf\left(\frac{L}{R}+\frac{2s}{R}\right) \quad \ldots (5)$$

(2) holds for both axles in outer contact, thus $a=b=\frac{R}{R+s}$; (3) for either axle in outer contact, and the other on the middle of the line; (4) for a diagonal position, thus $a=\frac{1}{b}=\frac{R}{R+s}$, or $=\frac{R+s}{R}$, or for the wagon set fairly on the middle of the line, thus $a=b=1$; (5) for inner contact of both axles, thus $a=b=\frac{R+s}{R}$.

For investigation of actual resistances and wear, the position assumed by the wagon under the conditions that generally hold in practice must be ascertained. Experience proved that the front axle of a wagon with rigid wheel-base always ran in outer contact. Theory shows that it could only be otherwise if the wheel-base were $<\frac{1}{2}$ the gauge. Less was known of the behavior of the hind axle; to solve the question trials were made on a line with curves of radii down to $8\frac{1}{2}$ chains, with wagons of 16.4 and 8.2 feet wheel-bases, in which an arrangement of mirrors showed the play between flange and rail to occupants of the wagon. It was found that the tendency of the hind axle to run in inner contact was much greater for the long than for the short wheel-base; for the latter indeed it ran in outer contact when the curvature was small. Reasons are then given for assuming the law, that the hind axle of a four-wheeled wagon with rigid wheel-base always takes a radial position if sufficient play be provided on the line. Its accuracy was confirmed by experiments with a model. Hence the distance between outer rail and outer flange of hind axle

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being the height of a chord equal to twice the wheel-base is

$$\sigma_h = \frac{L^2}{2R} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

but if σ the whole play be $< \frac{L^2}{2R}$, then:

$$\sigma_h = \sigma \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and corresponding to these values of σ_h we have for the sine of the angle of contact of outer front wheel

$$\sin \beta = \frac{L}{R} \quad . \quad . \quad . \quad . \quad (8)$$

or $$\sin \beta = \frac{L}{2R} + \frac{\sigma}{L} \quad . \quad . \quad . \quad (9)$$

The constraint necessary to alter the position of a wagon turning a curve arises partly through the axle seats, but chiefly from the lateral pressure between the rail and the outer flange of the front axle. For the former the maximum value is $K_1 = Gf\frac{s}{R} \times f_1 \frac{d}{2r}$, where f_1 is coefficient of friction between axle and axle-seat, d diameter of an axle-arm, and r radius of a wheel; this is a consequence of the geometrical connection of the axles and wagon. The expression for the lateral pressure is

$$P_a = G\left\{\frac{f\left(1 + \frac{s}{2L}\right)}{\cos \beta} + \frac{V^2}{gR} - \left(\frac{h}{s} + \sigma \tan a\right)\right\},$$

where V is the velocity, g the acceleration for gravity, h the cant of outer rail, and a the angle of conicity of the tires: here no allowance is made for friction between flange and rail, but if f_2 be the coefficient, and the actual place of contact be considered, we have for lateral pressure, $K_2 = \frac{0.9 \sin \beta}{r} P_a \times f_2$. The three members of P_a are due to the force to make the front axle take its altered position, centrifugal force, and the force arising from cant. The total curve resistance is $K\gamma = K + K_1 + K_2$, and for a diagonal position of the wagon with the front axle in outer contact, which is the position occurring in practice,

$$K\gamma = Gf\left(\frac{L+s}{R}\right) + Gf\frac{s}{R} \times f_1 \frac{d}{2r} + \frac{0.9 \sin \beta}{r} P_a f_2 \quad . \quad . \quad . \quad (10)$$

where the values may be $f = \frac{1}{7}$, $f_1 = \frac{1}{3 \cdot 5}$, $f_2 = \frac{1}{3}$, and the second member may, in most cases, be neglected. K_1 and K_2 have not, to the author's knowledge, been taken into account hitherto. K arising from horizontal shifting causes wear of the rail tops, and affects the inner rail most; K_1 causes wear of the axle seats and holders only; K_2 resembles the action of a blunt cutter, the flange of the outer front wheel being the cutter, and the inside of outer rail the object cut. For carriages in a train the value of P_a is altered by forces in the couplings, and the author investigates this effect minutely.

Dealing next with six-wheeled carriages, if to the middle axle no more than the necessary play be given by thin flanges, cylindrical are better than conical tires; but with the usual spread of gauge at curves no lateral play is required for the middle axle. If there be no spread of gauge, safety requires a lateral play of 0.2 inch only for a wheel-base suited to the curve; but a wheel-base of 19.7 feet would require 0.8 inch on a curve of 8.5 chains radius. Supposing the loads G on the end axles equal, and that on the middle axle a fraction n of each of these; so that, Q being the weight of the carriage, $G = \frac{Q}{n+2}$ and $G_m = \frac{nQ}{n+2}$, the whole resistance is—

for inner contact of middle axle:

$$K''' = \frac{Qf}{R}\left\{\frac{(L+s) + n\left(\frac{L}{2} + s\right)}{n+2}\right\} \quad . \quad (11)$$

for outer contact of middle axle:

$$K''' = \frac{Qf}{R}\left\{\frac{(L+s) + n\frac{L}{2}}{n+2}\right\} \quad . \quad . \quad . \quad (12)$$

Comparison of these equations with (4) shows that a six-wheeled rigid-axled carriage passes curves with less resistance than a four-wheeled one of equal weight and wheel-base, if the middle axle can run in outer contact, but with greater if its play allows only of inner contact. The minimum lateral play required to allow the middle axle run in outer contact is $\frac{L^2}{8R} + \frac{\sigma}{2}$.

The cant of the outer rail, when

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adapted to neutralize centrifugal force, is obtained from the equation

$$h=s\left(\frac{V^2}{gR}-\sigma\tan\alpha\right) \quad . \quad . \quad . \quad (13)$$

After treating generally of the question of spread of gauge, the author sums up with the conclusions:—1. Four-wheeled wagons with rigid wheel-base pass curves with greater safety when there is no spread of gauge, and the flanges are unworn, since the angle of contact is then diminished by half: 2. Such wagons run on curves of the minimum radii for their wheel-bases, and with the usual spread of gauge, with the hind axle in inner contact, and with less constraint than if there were no spread of gauge: 3. With the usual spread of gauge the curve resistance is less for worn-out than for unworn tires.

Security is dependent on the relations existing for the outer front wheel, and is greater—the greater the vertical, the less the lateral pressure, the smaller the angle of contact, and the more sharply rounded and vertical the places of contact between flange and rail.

The curve resistance and wear are less—the less the vertical and lateral pressure, the less the angle of contact, and the nearer the places of contact between flange and rail lie to the crown of the rail, and for the least possible rounding of these places.

A table is given with corresponding values of R, L, V, h, σ, ρ, lateral pressure, and total curve resistance of four-wheeled wagons and locomotives with rigid wheel base.

Arrangements for facilitating the use of longer carriages on curves are next considered. When a carriage constructed on the American bogie system runs on a curve, each car will clearly follow a tangential direction till it runs against the outer rail, and then assume the position natural to a rigid-axled wagon. Owing to the smallness of the distance $\frac{l^2}{2R}$ (l being the bogie wheel base) of the hind axle of each car from the outer rail equation (2) holds approximately for each; hence the whole curve resistance to produce the altered direction of the carriage is $2\,G_1 f\frac{L}{R}$, G_1 being the load on a single car axle. If, again, for a locomotive, a bogie be used in front, with a rigid axle behind, the resistance, though less than for a rigid four wheeler, is large compared with the value just given. Since bogies with more than one axle have the disadvantage of complication, and for locomotives of reducing the load on the front outer wheel, numerous systems of flexible single axles have been devised. Of these the Adams guided axle, and the Bissel front axle for locomotives, have been laid aside on account of their dependency for steady motion on the presence of two rigid axles of long wheel-base.

Mr. John Clark devised a three-axled wagon, used on Mount Cenis, in which the axle boxes were so connected by mechanism that the yielding of the middle axle through the height of a chord equal to the wheel-base caused the end axles to run radially. If λ denote the yielding of the middle axle, Φ the angular turning of the end axles, since $\lambda=\frac{L^2}{8R}$, and $\sin\Phi=\frac{L}{2R}$, the condition to be fulfilled by the mechanism is $\sin\Phi=4\frac{\lambda}{L}$, which shows that it will suit curves of any radius. With this, and the Cleminson system on the same principle, the curve resistance and lateral pressure can be almost totally removed.

For a locomotive with the Nowotny front axle, which differs from the Bissel axle in having the pivot above the middle of the line joining the wheel centers, instead of being somewhat behind this position, experience has shown that the duration of the front tires, and proportionally of the rails, is four times > for a rigid axled locomotive of the same wheel-base.

In the search for a simple system of flexible axles for wagons, the central pivot being laid aside, an arrangment allowing the journals with their covers to slide in the long direction of the wagon against single or double incline seats in the boxes, with a central holder to neutralize shocks, was adopted with success. A simpler method lay in providing suitable play between axle box and holder, with the necessary turning power between bearing spring and axle box. Several forms of couplings for flexible axles are shown by drawings.

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ON THE CONSTRUCTION, PERFORMANCE, AND WORKING OF LIGHT RAILWAY LOCOMOTIVES.

By Hr. VON BORRIES, of Hanover.

Foreign Abstracts of the Institution of Civil Engineers.

THIS is an essay towards settling the conditions, leading dimensions, &c., of engines for working "secondary" or light railways, based on the general principles laid down in Germany for the construction of locomotives, and the building and working of light railways. Three different gauges are considered throughout, viz.: standard gauge (4 feet 8½ inches), meter gauge (3 feet 3⅜ inches), and ¾ meter gauge (2 feet 5½ inches).

Load per Axle.—This is the first element to be fixed in all rolling stock. In light railways the rails are proportioned to the heaviest goods wagon which will run on the line, and the weight per axle of the locomotive must conform to this. With standard gauge, where main line wagons may come over the line, the load per axle should be taken at 9 tons; with meter gauge at 7½ tons (taking 10 tons as load of wagon, and 5 tons as its weight); with ¾ meter gauge at 3¾ tons (5 tons for load, 2½ tons for weight of wagon). These figures agree with the rules of the German Railway Union, except that they give 5 tons for ¾ meter gauge, which seems excessive.

General Principles. — The leading principles should be simplicity of construction and facility of maintenance. The blast pipe should be retained, as the most economical and automatic method of forcing the fire, and the condensation of the steam, sometimes insisted on in populous districts, should be avoided as much as possible, on account of the expense. The engines should be tank engines, four-coupled or six-coupled, according to the work to be done. They should be no heavier than is required to produce the requisite tractive force by adhesion, and the speed on steep gradients should be lowered so that a boiler suited to this weight may generate the needful amount of steam. For very steep gradients, the requisite weight may be obtained by using special engines, designed to carry luggage or passengers as part of their load.* A four-coupled engine is to be preferred, unless the traffic is heavy, or the conditions unfavorable. The train officials should be reduced in number as far as possible, since each may be taken to absorb in wages from 6 to 15 per cent. of the working cost. On light railways the full services of both driver and fireman are not needed for the engine, and therefore the latter may also act as a brakesman, working not only the engine brakes, but also those in the front van, which should be placed in communication with the engine. The guard would also act as a brakesman for his own van, which should always be at the rear of the train, and no other brakesman would be necessary. Continuous brakes are not worth their expense, especially looking to the probability of goods wagons being mixed in the train; but, as a provision for emergency, such goods wagons may be fitted with lever brakes on the Exter system, which may be worked from the engine by means of a cord. The engines should have a gangway at each side, and provision at each end for stepping on to an adjoining vehicle.

Provisions against Fire and against the frightening of Horses.—The danger of fire must be completely obviated by proper spark catchers or extinguishers, and by closing in the ash pan, so that no cinders can escape. Horses are found to be frightened mainly by the sight of a carriage apparently running of itself, by violent puffs of smoke or steam (not the mere escape of steam at the chimney), and by rapidly moving gear. These causes can be removed to a great extent, if not entirely, by boxing up the gear, by placing an air vessel in the exhaust pipe, and by turning the escape from the cylinders and safety valves into the con-

* *Vide* Minutes of Proceedings Inst. C.E., Vol. lxi., p. 369: "Van Locomotive."

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denser, and that from the injector into the tank.

Leading Dimensions.—The engines are taken to weigh about 90 lbs. per square foot of heating surface; it being assumed that they are built on the Krauss system, and that the grate surface and tank capacity will be varied according to the gauge. The useful steam generated is taken at 5 lbs. per square foot of heating surface per hour, with a pressure of 150 lbs. The latest cut-off, on the steepest gradient, should not exceed 0.4 of the stroke, which gives mean pressure = 97 lbs., and work done per pound of steam = 102,000 foot-lbs. The adhesion co-efficient, with sanded rails, may be taken at 0.15; whence, assuming that the engine may lose 11 per cent. of its full weight, through consumption of fuel and water, the tractive force may be taken as 0.133 of the full weight. The wheel diameter for standard gauge may be taken as 3 feet 3 inches, the same as for the carriages, which, at 18 miles an hour, the maximum speed, gives 2.8 revolutions per second. For the narrow gauges the speed should not exceed 12 to 15 miles an hour, and the diameter of the wheels may be from 2 feet to 2 feet 8 inches. The length of stroke should be about half the wheel diameter. The cylinder diameter may be calculated (for metric measures) from the following equation:

$$d_1 = 0.011 \times \frac{\text{Tractive force}}{3.4}$$, where 0.011 is Koch's value for the co-efficient of machine friction in locomotives. The grate surface should be as large as possible, say $\frac{1}{50}$ heating surface for standard gauge, $\frac{1}{60}$ for meter gauge. The tank may hold 3½ cubic feet, and the bunkers 1.1 cubic feet, per ton of engine weight. The above and other leading particulars are combined in the following table:

TABLE I.—LEADING DIMENSIONS.

Gauge	Standard.		Meter.		¼ Meter.	
Number of wheels	4	6	4	6	4	6
Full weight.....tons.	18	27	15	22½	7½	11.3
Heating surface.....sq. feet.	430.	646	355	538	177	269
Grate..... "	7.6	12.9	6.0	9.0	3.0	4.5
Pressure.....lbs. per sq. inch.	150	150	150	150	150	150
Diameter of wheels.....inches.	39	39	31.5	31.5	24	24
" " cylinder..... "	11.0	13.4	9.9	12.2	7.1	8.7
Stroke " " ..... "	19.5	19.5	15.7	15.7	12.0	12.0
Capacity of tank.....cubic yards.	2.9	4.2	2.15	3.25	0.98	1.45
" " bunkers..... "	0.7	1.0	0 6	0.9	0.3	0.45
Wheel-base.....feet.	8.2	9.8	6.6	8.2	5.25	6.6
Tractive force (without friction)...tons.	2.4	3.6	2.0	3.0	1.0	1.5

Performance of the Engines on various Gradients.—The various figures assumed above give an effective power for the engine of about 6.3 HP. per ton weight. The tractive force per ton weight, including friction, will be about 321 lbs., whence it is calculated that the speed required to develop the maximum tractive force is 7 miles an hour; and this should therefore be taken as the speed on the steepest gradient of the line. On this assumption the maximum haulage load on various gradients, exclusive of the engine, is given by the table on next page.

Working.—The cost of fuel and repairs may be greatly diminished on light railways, by keeping the speeds on gradients below the steepest at a proper limit; the principle being that the generation of steam should never be faster than it is on the steepest gradient. If this gradient is greater than 1 in 100, the evaporation, with lighter gradients and higher speed, will remain about the same. If it is less than 1 in 100, the evaporation diminishes rapidly on lighter gradients, and the speed must therefore be regulated by some positive limit, which in Germany is 18 miles an hour.

The gross consumption of water per hour may be taken at 6.5 lbs. per square foot of heating surface, or 0.075 of the weight of the engine. The total weight of water in the tank may be taken at 0 1 of the engine weight; and, assuming

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TABLE II.

Gauge.	Weight of Engine.	Tractive force.	Maximum weight (tons) of Train on gradient of									
			1 in 200	1 in 150	1 in 100	1 in 80	1 in 60	1 in 50	1 in 40	1 in 30	1 in 25	1 in 20
	Tons.	Tons.										
Standard	18.0	2.4	320	255	180	146	110	91	71	50	39	28
	27.0	3.6	475	385	270	220	166	136	116	75	59	42
Meter...	15.0	2.0	265	213	150	122	92	75	59	42	33	24
	22.5	3.0	400	320	225	183	128	114	89	63	49	35
½ Meter.	7.5	1.0	132	107	75	61	46	38	30	21	16	12
	11.3	1.5	200	160	113	92	70	57	45	31	25	18

that one-quarter of this should be reserved for emergencies, it would follow that the watering stations should be one hour's distance apart. But this assumes that the engine will always be exerting its maximum power, and, taking this and other circumstances into consideration, the watering stations may be placed at about double the above distance. They should be of the simplest character, generally consisting of a well from which water may be drawn by an ejector or pulsometer, worked by the engine. It is only at the engine sheds that a tank is necessary, and this may be filled by means of the steam left in the engines when they come in. As to the distance between the coaling stations, assuming that each pound of coal will evaporate 8 lbs. of water, and that the capacity of the bunkers is only one-quarter that of the tank, it will follow that this should be double the distance between the watering stations.—*Glaser's Annalen.*

ESCAPE FROM A SECOND TAY BRIDGE CATASTROPHE.

From "The Builder."

THE banks of the Solway are the birthplace and the home of legend. The region is resonant with ballad. The magic of nature seems to have prepared a scene for the magic of romance. The craggy heights of Criffel look down on a noble estuary. The tourist who views the spot from the lofty top of Skidaw sees fertile plains divided into numerous enclosures that look like gardens, while the river, when the tide is in ebb, traces a fivefold line to the sea. On either side are brown and glittering sands. Then come two converging lines of turbid water; and in the center is a narrow streak glittering like silver. Nor are the charms of the natural scene all that add interest to the spot. Over the broad expanse of sand the sea sometimes comes up in flood as fast as a horse can trot. And in the little fishing village of Allonby, when stormy weather is at hand, the hills of the Isle of Man may often be distinctly seen, although such vision is but the effect of mirage. High country intervenes between the shore of the Solway and the western coast of the Irish Channel, so that the appearance of this natural portent is in itself a phenomenon fitted to dispose the mind to the ready acceptation of the marvelous. Nowhere in the British islands, except from the hills to the east of Cork, have we ever witnessed the rare deception of the *fata morgana* so plainly as on the banks of the Solway.

On the last day of January, in the present year, the Solway very narrowly escaped becoming the scene of a calamity that would have been without a precedent in all the ghostly tales of border lore. It was due to the simple, old-fashioned, often derided precaution of the night watchman that the evil fame of

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the Solway viaduct has not rivaled the discredit of its sister structure across the Tay—sister, that is to say, in object and in fate, albeit presenting little family likeness in appearance; indeed, the very opposite principles have been adopted for crossing the two estuaries. In the Tay bridge the central girders spanned openings of 245 feet wide. In the Solway bridge the spans are only 30 feet. Thus eight piers have to be reared in the latter structure, for one on the former. The height and cost of the girders, which, on the Tay bridge were 27 feet deep, are proportionately diminished. The Solway bridge would have felt almost nothing of the storm which blew down the Tay bridge. But the Tay bridge would have been but little affected (or might have been but little affected) by the islands of floating ice that crushed so many of the light and frequent piers of the Solway viaduct.

The Solway bridge has been open for traffic for above twelve years; it ought, therefore, to be all the more remembered, to the credit of the officials of the railway company, that on the setting in of the thaw the bridge was carefully watched. The accounts at present received do not mention when the traffic over bridge was suspended. It is, however, evident that no trains were allowed to attempt to cross the Solway on the night of the 31st, for had such been the case, the catastrophe of the Tay bridge would have been exactly repeated. So loud were the crashes of the ice against the piers of the bridge in the course of the night, that it was feared that serious damage had occurred. By daybreak it was seen that five of the piers, each consisting of five hollow columns, of 12 inches diameter, had been destroyed, although the continuous line of girder and platform was so well bolted together as to be unbroken. Some of the other piers had been damaged; one, indeed, had been damaged on the 29th. On the night of the 31st further damage was done to the structure by the masses of ice borne by the high tides, and on the morning of the 1st instant a complete gap was made, to the width of 90 feet. This is about 600 yards from the Scottish or northern end of the viaduct. Nearer the Cumberland coast is a yet wider breach, extending, it is said, to the width of nine of the 30 feet spans. The bridge was veiled in a dense fog through the night, and the damage done was not fully ascertained on the morning of the 1st.

The length of the viaduct is stated at 1,960 yards, and as the waterway is also given as 5,666 feet, only the width of 12 inches is allowed for each pier. In fact, the supports of the girders appear to have been simple rows of iron columns, of 12 inches diameter, five in a row. These are described as sunk into the bed of the Firth to an average depth of 16 feet, the height being from 35 feet to 40 feet. If this be correct, it would seem difficult to design a mode of supporting a river bridge which would form a more effectual ice trap. A great number of feeble columns, planted at the narrow intervals of 30 feet, afford a positive invitation to danger from ice or floating wreck. The only things to cause surprise are: How could the Board of Trade have sanctioned such a structure? and, How is it that it has stood so long?

It is curious that in the mode of crossing these two important estuaries such opposite ideas of economical structure should have been carried out. No doubt the height of the rails above the sea had much to do with this, as the Tay bridge, if the accounts are accurate, was three or four times as high as the Solway bridge—as high, that is to say, measured to the level soffit; for the depth of the 245-feet girder was, of course, much more than that of the 30-foot girder. But if the height were fourfold, it is hardly a justification for an eightfold difference in the span. In point of fact, spans of 30 feet form almost the cheapest possible arrangement for a long viaduct. Where the expenses of obtaining foundations are great, this circumstance has to form the basis of a comparative calculation. In other respects, while the cost per foot super. of the platform, rails, &c., is the same for all spans, the cost of the main girders is almost directly as the squares of the spans. In the Solway bridge the simple and inexpensive character of the piers was such as to allow of the reduction of the span to the narrow width before stated. But the economy was a pitiable one which dotted the bed of the Solway with rows of feeble columns, which

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any hard winter menaced with overthrow.

It is a remarkable circumstance that, in two cases presenting so close a parallel, the pursuit of economy has led to the exposing of the several structures to the destructive action of two natural forces against each of which the engineer had ample warning to provide. For what may be called a new danger in the history of bridge building, the engineer of each viaduct indeed provided. The Roman engineers, and the French and Italian architects, who reared the great bridges, viaducts, and aqueducts which form some of the marvels of European architecture, never contemplated having to design structures that could support trains of carriages of hundreds of tons weight, whirling along at a speed of from ten to fifty miles an hour. The weight that could come on a Roman bridge was comparatively small. The effect of wind pressure, even in such cases as the Pont de Gard, or the lofty Alcantara aqueduct, was not formidable against the weight of the solid masonry of piers and arches. Of the three elements of overthrow against which the old bridge builders had to provide, viz., moving weight, pressure of storm, and shocks from floods or from floating bodies borne down by floods, no doubt by far the greatest amount of attention was given to this last-named risk. In Old London Bridge, as we have mentioned in another place, there were 10 feet of pier to 7 feet of arch. When the engineer attempted to cross a deep estuary by gigantic strides, he forgot how great a destructible surface he exposed to the fury of the wind. On the other hand, when he attempted the same task by short and numerous steps, and thus provided in the most economical way for the support of moving weight, and produced a structure that could defy the wind, he forgot how liable were his numerous and slight supports to be swept away by ice, or by any floating matter dashed against them by tide or by current.

It is not to the credit of our practical architectural knowledge that we find, on the two opposite coasts of Britain, one bridge builder falling into Charybdis, while the other falls into Scylla. Economy is a great point for the architect t study. But it must be a wise economy. The first oversight committed by the great bridge builders of the railway times was that these structures were insufficient to bear the weight of their own thrust, or the weight of their own material, combined with that of a passing train. It ought to lead us to view other errors with much consideration, to reflect that two of the first engineers that our country produced had to learn the imperfections of formulæ on which, together with their brethren, they relied, by failure. Mr. Brunel's Maidenhead bridge fell down by its own weight when the centers were struck. Mr. Robert Stephenson's Dee bridge broke down with the first train that came on it after it had been covered with a coating of gravel. So that when we add to these the Tay bridge, fairly torn from its piers by a hurricane, and the Solway bridge, with its legs knocked from under it by floating ice, we have practical warning of the force of the three chief different dangers with which, as before said, the bridge builder has to contend. May we not hope that the fourth catastrophe may cause all concerned to put to themselves the question whether, in looking to cheapness, they have provided against every source of danger? And we must add that a special warning has been given to look to the soundness of all great viaducts, more especially those made of iron. The loss incurred by the destruction of the Solway bridge is very heavy. Watchfulness prevented it from being fatal. We should like to be convinced that there are no other cases in which very probable causes of danger have been overlooked in construction, or in which rust, vibration, or molecular change has not been allowed to make silent inroads on the margin of stability.

The manufacture of tin plates originated in Northern Germany, and as a trade had existed many years in Bohemia. From Bohemia, in 1620, it was carried into Saxony by the Duke of Saxony, and from Saxony the secret came to England in 1670 and was tried at Pontypool, but was given up and neglected until 1720, up to which date our ancestors had imported tin plates from Hamburg, though tin had gone from our shores to other countries. —*English Papers.*

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EXPERIMENTS ON THE ACTION OF FATS AND MINERAL LUBRICANTS ON IRON, IN THE PRESENCE OF HIGH-PRESSURE STEAM.

From "Abstracts" of the Institution of Civil Engineers.

It is well known that steam of high temperature decomposes natural fats, and causes free acids to separate from them. When used as lubricants, in cylinders employing high-pressure steam, the resulting acids corrode the metal surfaces with which they come in contact. With steam of very high pressure, this takes place with great rapidity; with steam of medium pressure it continues, though to a less degree; but it goes on also even in the damp atmosphere, as is proved by fats turning rancid when exposed to the air. In engines provided with surface condensers, the result may be serious injury to the boilers; for the fats carried away from the cylinders with the exhaust steam, are returned to the boilers in the feed-water and are there decomposed. The continuous action of hot steam causes also the generation of volatile acids, which leave the boiler with the steam, and injuriously affect steam pipes and cylinders. In this way the speedy destruction of boilers fed from surface condensers is generally accounted for. Some persons attribute this destruction, to a certain extent, to the use of distilled feed-water. In consequence of all this, mineral oils, which consist chiefly of hydro-carbons, and which do not suffer decomposition at the ordinary temperature of steam boilers, have come into use, although as lubricants they are far from efficient at high temperatures. One circumstance should, however, be mentioned, which somewhat diminishes the usefulness of mineral oils, viz., at high temperatures mineral oils adhere to the sides of the cylinders less than water does, and consequently, when steam is shut off, the condensed water rusts the surfaces more than it would do, were animal fats used. The following experiments were all made in consequence of the remarkable results given by the following analysis of the sediment deposited in the surface condenser,

—	I. Deposit from Condenser.	II. Deposit from Cylinder.	III. Deposit from Boiler.
	Per cent.	Per cent.	Per ct.
Water	10.59	0.23	0.88
Mineral oil	86.29	18.43	1.50
Fatty acids	24.19	2.70	0.58
Neutral fats		2.14	0.12
Copper (In the metallic state)	1.78	2.11	—
Lead (In the metallic state)	1.08	0.50	—
Zinc (In the metallic state)	0.30	0.40	—
Iron (In the metallic state)	7.37	21.44	—
Oxide of iron	16.0	46.58	74.26
Peroxide of iron	—	—	14.68
Gypsum	0.32	trace	5.34
Salt, common	0.74	trace	1.93
Organic dirt	2.98	2.58	0.58
Inorganic dirt	1.79	2.89	trace

cylinder, and boilers of a marine engine. The lubricants used were, first, tallow, and then, till the day of the experiments, mineral oil. The metal found in the deposit existed in the state of very fine dust, which preserved its metallic brightness perfectly. The iron was in such a minute state of subdivision that, after separation from the compound, it burnt spontaneously with a bright red heat on exposure to the air. These particles of metal were of course produced by the friction of the piston, etc., and it is a matter of special importance to observe that, in spite of their minute subdivision, and prolonged exposure to the oxidizing influence of water and steam of high temperature, they were, nevertheless, perfectly free from oxidation. Apparently the remains of the lubricants had preserved them; and hence the question arises—in opposition to the commonly received views—to what extent do these residues of the lubricants preserve metals from the oxidizing influence of water and steam?

To solve this question a strong copper boiler was made use of, connected by means of a pipe with a receiver, having

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a screwed top. Into the receiver were placed small vessels, which contained the metal plates and the different lubricants to be experimented upon; so that any differences in the corrosion of the plates could only be ascribed to the action of the lubricant. The pressure in the boiler was maintained at from two to three atmospheres above the air pressure. The test-plates were accurately-weighed pieces of boiler plates, which, after the experiments, were thoroughly cleaned and again weighed. The difference in the weights gave the amount of iron lost by oxidation. The experiments were made with both sea and distilled water. The plates were half immersed in the water, their surfaces having been painted with the lubricating material, a little of which was also poured on the surface of the water. The following table gives the results:

No.	Length of Experiment. Days.	——	Weight of Plate in milligrammes. = 0.0154 grain.		Loss of weight in milligram'es.
			Before the Experiment.	After the Experiment.	
1	2	In sea water	32564.0	32519.0	45.0
2	2	" " with tallow	32386.0	32375.0	11.0
3	2	" " " mineral oil	29961.5	29954.5	7.0
4	6	" " (no lubricant)	32228.5	32050.0	178.5
5	6	" " with tallow	32198.5	32171.0	27.5
6	6	" " " mineral oil	29814.5	29796.0	18.5
7	6	In distilled water	31907.0	31867.0	40.0
8	6	" " " with tallow	32126.0	32115.0	11.0
9	6	" " " " mineral oil	29751.0	29734.0	17.0
10	6	" " " (no lubricant)	29693.5	29652.0	41.5
11	6	" " " with tallow	31775.5	31764.0	11.5
12	6	" " " " mineral oil	32066.0	32050.5	15.5

Experiments 1 to 6 prove that sea-water alone and its steam destroys iron more rapidly than when tallow and mineral oil are present. The tallow, when fresh, contained 0.4 per cent. free acid, and after six days' exposure to steam, 3.4 per cent. Experiments 7 to 9 prove the same thing with regard to distilled water, and prove also that distilled water is less harmful than salt water.

In experiments 10 to 12 the plates, which were before exposed to the pure distilled water, were now coated with the lubricant, and *vice versa*, but without altering the result.

The oft-observed fact, that boilers of engines provided with surface condensers have a very short life-time, must therefore be ascribed to some other effect of the lubricating material than the generation of acids, for it has been proved above that, in spite of the presence of acids, the lubricants tend to preserve the plates from rust.

The following reason is advanced by the author to account for the destruction of the boilers, no account being taken of the direct action of the acids. When the lubricants come into the boiler, and acids are formed, these latter, acting on the lime and other alcalic minerals in the feed water, form insoluble soaps, which are deposited on the sides and bottom of the boiler, furnaces, etc. Furthermore, the fatty acids, acting on the oxide of iron contained in the feed-water, or existing on the boiler-plates, form insoluble iron soap, which also is deposited in a similar manner. These soaps are non-conductors, and in consequence the plates which are covered by, and which are also exposed to the action of the fire, are overheated and rapidly destroyed. An illustration of this action may be obtained by boiling sea-water in a platinum basin, over a moderate steady flame. Under these circumstances the boiling proceeds quite quietly. Let now a few drops of an oil rich in acids be dropped on the water; after a few moments the

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steady boiling ceases, and violent ebullition and foaming takes place. The bottom of the basin will be found to be covered with a thin layer of soap, which the water cannot touch.

The author carried out a series of experiments to determine the relative values of tallow and mineral oils as preservatives for iron, under conditions which obtain in boilers. The result was that the mineral oils proved incomparably the best. When tallow is used, the result is satisfactory for the first few days, but as the formation of acids steadily progresses, so the oxidation rapidly increases. As a result of his researches, the author recommends that, wherever the lubricating qualities of mineral oils suit the circumstances, they should be used with engines provided with surface condensers; but in the case of ordinary condensers, and non-condensing engines, tallow may be used without any ill effect, as it passes through the cylinder before there is time for acids to form, and consequently the metal surfaces are not exposed to any injurious action.

THE INJECTOR AS A MOTOR FOR HYDRAULIC LIFTS.

By Hr. OTHEGRAVEN.

From "Abstracts" of the Institution of Civil Engineers.

THE author remarks that the advantage of using hydraulic power for the lifting of heavy weights through short distances has long been recognized; but an important objection is the necessity of special plant (engines, pumps, accumulator, etc.) to generate the motive force. This plant, besides its cost, is often difficult to find room for; and if located in some corner of a large shop, the distance to which the pipes have to be carried is a serious drawback. In such pipes frost is often a danger, where they cannot readily be buried, and the fact that the need for such tools is often occasional only makes another difficulty. These objections are obviated by using the ordinary injector to supply the motive power. An injector in good working order will raise water to a pressure about 50 per cent. higher than the steam pressure by which it works. It is therefore only a question of the most convenient method of application. It may be sufficient in many cases to use the actual injector of a locomotive, connecting its outlet direct to the pressure cylinder; but since this connection takes time, it is better to have a portable injector fixed to a small water tank. This injector is connected by flexible tubing to the pressure cylinder at one end, and to the locomotive boiler at the other; the attachment to the latter being made at the opening of the overflow pipe of its own injector. The steam valve of the engine injector is then opened, and the delivery valve closed; the steam is therefore obliged to pass through the opening of the overflow pipe to the portable injector, and thence to the pressure cylinder. Using this arrangement, with a steam pressure of 150 lbs., and with a pressure cylinder of 0.7 meter diameter (27½ inches) one man can with ease lift and turn on a turntable a locomotive of 35 tons weight, using its own steam for the purpose. The water is at once let off, when required, by opening a cock. The method may also be applied for tipping coal wagons on wharves; the engine which shifts the wagons supplies the steam in this case, the making and breaking of the connection being so easy that no time is lost. Another arrangement consists of a portable pressure cylinder slung from an elevated beam, and is used for lifting wheels and axles out of a sunken road, which has been done by this means in one-ninth of the time it formerly occupied. Yet another is a portable cylinder of 420 millimeters, diameter (16½ inches), taking the place of a hydraulic jack in cases of derailment, etc. In all these cases the principle is the same, viz., to use the steam of the nearest available boiler (especially a locomotive) to generate the required pressure by means of an injector just as it is wanted, instead of fixed pumps and accumulators to maintain the pressure continuously.—*Organ fur die Fortschritte des Eisenbahnwesens.*

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DEEP-SEA INVESTIGATION, AND THE APPARATUS EMPLOYED IN IT.

By J. Y. BUCHANAN, F. R. S. E., F. C. S.

From the "Journal of the Society of Arts."

DEEP-sea investigation, in the sense of exploring the surface of the ocean with the view of discovering new lands, and so determining the boundaries of the sea, has, in all ages, commanded the attention of the more civilized races of mankind, and the most adventurous of their members have ever engaged with enthusiasm in its pursuit. It is probable that the first voyages were undertaken, less with a view to satisfy curiosity, than to render traveling from place to place more expeditious and less irksome. It was not until the mariner's compass had been introduced into Europe, in the 12th century, that long voyages, out of sight of land, could be undertaken; although the enterprise of the Mediterranean mariners enabled them to take their ships as far as Britain without any such aid; and no one who is at all acquainted with practical navigation, will deny the difficulty and the danger of the undertaking. The adoption of the compass as a standard of direction, and the immense amount of valuable property which was consequently risked on the faith of its infallibility, raised a strong interest in the study of the behavior of the magnetic needle in different localities, especially at sea, resulting in the discovery and investigation of the magnetic variation which, consequently, became a recognized phenomenon, to be taken into account in all questions affecting a ship's reckoning. During his voyage, which ended in the discovery of America, Columbus crossed and determined the position of a line of "no variation" somewhat west of the Azores. This line was, by Papal decree, made the boundary between the rival kingdoms of Portugal and Castille, and thus, to the determination of its position, was given a factitious importance which was the indirect cause of much valuable geographical discovery. The first voyages for scientific purposes were thus undertaken for determining the magnetic constants at different places on the ocean, and as these are subject to continual variations, their re-determination from time to time is likely to furnish, in the future, a motive for frequent maritime expeditions.

It was in connection with the investigation of magnetic phenomena that an exceedingly convenient method of graphically representing the relation between isolated observations, received its first extension. In an ordinary map or chart, one of the principal features is the coast line. This line represents the most probable direction of the intersection of the sea surface with the land surface, as deduced from observations at isolated points. With greater detail in the survey, the height of points inland above the sea is determined, from which profiles are drawn, and points of equal height on these profiles are connected, and their projections on the sea surface are entered in the map as lines of equal height above the sea, generally called contour lines. When the depth of the land below the sea is determined, the same method of graphic representation is adopted. In a chart, however, all the original determinations of depth are entered, while in the map the general configuration of the country is represented as deduced from the individual observations. Similarly, in rendering the results obtained by the magnetic observer conveniently and intelligibly accessible to the public, and especially to the navigator, the results of the determinations of variation at the different localities are entered in a chart, and points of equal variation are connected by lines drawn at convenient intervals, as from degree to degree, or every five degrees. Here the case of sea and land charts is reversed. At sea the magnetic constants vary gradually, and nowhere abruptly, consequently a chart of magnetic contours of moderately recent date supplies all the wants of navigation. It is other-

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wise, however, on land, especially in volcanic countries, or those consisting largely of igneous rocks. An almost constant constituent of these rocks is magnetic oxide of iron or loadstone, and the proportion in which it is present in rocks, immediately adjacent to one another, often varies within very wide limits. The consequence is, that the needle points in different directions at localities close to each other, so that a survey of such a country would differ very materially, according as the bearings were dependent on solar or magnetic observations.

The employment of contour lines to represent the results first of geodetical, then of magnetic, observations, was extended by Humboldt to the representation of temperature phenomena. They have since been largely used to represent the distribution of other qualities, such as density of sea water, and of plants, animals, &c.

Important, however, as is the investigation of magnetic phenomena at sea, it is not my intention to refer further to it to-night; it is enough to have pointed out that the interest which it possessed for navigation was the moving cause of the fitting out of the earliest maritime scientific expeditions. Our concern is with the determination of the depth of the ocean, of the distribution of temperature of its waters, of the chemical and physical character of its waters, and of the ground at its bottom, and with the distribution of life in it.

The first problem of deep-sea investigation is to determine the extent of the ocean, its size, its volume. The superficial extent and limits are determined by the surveyor. In order to map out the bottom of the sea, there is only one method, namely, the direct determination of the depth at as many places as possible.

When a ship is "in soundings," the depth is ascertained at frequent intervals by a "leadsman" stationed in some convenient place on the outside of the ship, whence he can throw forward the lead attached to the line which he carries in his hand. The ordinary hand lead line is from 20 to 25 fathoms long, and it is conventionally marked with bits of leather at 2, 3 and 10 fathoms, white bunting at 5 and 15, red bunting at 7 and 17, blue bunting at 13, and with two knots at 20 fathoms. The lead is a long, finely tapered block, of generally 14 lbs. weight; it has a recess at the thick end, and is perforated at the other end for the reception of the line. This instrument is chiefly used while the ship is in motion. The man entrusted with the duty swings the lead backwards and forwards, and even completely round a vertical circle, in order to generate the requisite momentum to carry the lead well in advance of the ship before it touches the water. It then sinks rapidly, whilst the leadsman's position is advancing to the spot where the lead touched the water. When the line has thus been brought up and down, the depth is ascertained by observation of the marks on the line. It is obvious that by this primitive, but effective, method of sounding, the limiting depth which can be so ascertained depends chiefly on the speed of the vessel, and in a less degree on the skill and strength of the leadsman. Under ordinary circumstances, the method is effective in depths up to twelve or fifteen fathoms, and this degree of efficiency suffices for most purposes.

Occasionally, however, it is advisable to sound in greater depths, without the ship being necessarily stationary. The simplest method of doing so is to reduce as much as possible the ship's way, and having carried the line well forward, to leave it there, and give it line as it sinks. Here the depth and the speed of the vessel should be so proportioned, that the lead reaches the bottom before the ship has passed completely over it. With care, very accurate soundings can be obtained in this way, but the depth must not be much above thirty or forty fathoms.

When the object is to sound in ocean water, where we must be prepared to meet with depths of two or three thousand fathoms, it is essential that the vessel be kept stationary, and if hemp line be used, much heavier weights must be employed. Sounding in great depths is one of the most important operations connected with deep-sea investigations, and it is only within the last thirty years that it has received any very great attention. Probably the first attempt at deep-sea sounding was made by Captain Constantine John Phipps, during his

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Arctic voyage, in the year 1773, when he was accompanied by Dr. Irving, who made a number of very valuable determinations of the temperature of the sea water at different depths, besides fitting the vessel with one of the earliest stills, which worked well, and supplied the crew with fresh water during the whole cruise. Phipps' deepest sounding appears to have been 683 fathoms. For this purpose, all the lead line in the ship was used, and a lead weighing 150 lbs., which appeared to have sunk about ten feet into the mud, a soft blue clay. With this was sent down a water bottle, of Dr. Irving's construction, and the water brought up had a pressure of 40° Fahr., that of the surface being 55° Fahr. The density of the water was also measured, and Cavendish's self-registering thermometers were used. So that, at this early date, the methods and objects of deep-sea investigations were perfectly understood. What prevented much work being done was chiefly the want of steam. But little advance was made in this branch of research until after the termination of the French war. In 1818, Captain John Ross made his well-known voyage of discovery to the Arctic seas, in H.M. ss. "Isabella" and "Alexander." During this voyage, he paid great attention to deep-sea investigation, and invented, and had constructed, one of the earliest satisfactory instruments for bringing up a considerable quantity of the bottom mud in deep water. He, himself, gives the following account of his instrument and its performances, in the appendix to the account of the voyage:

"This instrument was invented by me on board his Majesty's ship "Isabella" in the early part of our voyage to the Arctic Regions. Many fruitless attempts had been made to procure substances from the bottom of the sea in deep water, by the instruments with which we were supplied, and I had an opportunity of observing the reasons of this failure, which led to the discovery of that which I am about to describe, and which, in almost every instance, completely succeeded in accomplishing that desirable object, of bringing up substances of any description, in considerable quantity, from any depth; but it has also been found to preserve the temperature of any substances, if they are soft, until it can be measured by the thermometer, and by that means the temperature of the earth can be nearly ascertained at any fathomable depth. In Melville Bay, on the 1st of August, it brought up from four hundred and twenty fathoms some soft mud, into which the thermometer was immediately immersed, and it gave 29½°. At the same time, the self-registering thermometer, at the depth of two hundred and ten fathoms, gave the same temperature. In Prince Regent's Bay, in four hundred and fifty-five fathoms, it gave the same temperature. In the entrance of Lancaster Sound, at the depth of six hundred and seventy-four fathoms, the temperature of the mud was also found to be 29¼°; and at the highest part of that inlet in which we sounded, the mud was found to be, in six hundred and fifty fathoms, 29°.

"On the 6th of September, in latitude 72° 23′ N., and longitude 73° 07½ W., we sounded in 1,050 fathoms, from which depth the instrument brought up 6 lbs. of very soft mud. The next day being quite calm, we tried the temperature of the sea at five, six, seven, eight hundred, and a thousand fathoms, and found its temperature decrease from 35 gradually to the same temperature as the instrument gave it, which was 28¾. Although the instrument may not bring up the mud at the exact temperature of that at the bottom, it may be supposed that it cannot have suffered much alteration, from its agreeing so nearly with the self-registering thermometer, and that, if it has altered, it must be to increase the degree of temperature; hence, it may always be inferred that the mud at the bottom is not of a higher temperature than that brought up by the instrument. The reasons for so little alteration taking place is the closeness with which the instrument confines the mud, which is such as not to allow even the water to escape. If the instrument strikes among stones which are small enough to get between the forceps, it will bring up as many as are enclosed in them; in one instance, it brought up a stone (which weighed two pounds and a-half) from 300 fathoms, and, in another, it struck a rock and cut a piece out, which it brought up from 216 fathoms. The instrument was made from the model by the ship's

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armorer, and succeeded on the first trial.

"To use the deep-sea clamms, it is necessary to be provided with whale lines, such as are used by the Greenland and South Sea ships, which are two and a-half inches in circumference, made of the best hemp, and very pliable and easily coiled; the lines ought to be spliced together, and faked or coiled, so as to run quite clear on the fore part of the ship's decks. In very deep water it is necessary that it should be calm, or nearly so, to be certain that soundings are obtained in 500 fathoms; but, in a light breeze, the instrument may be hung to a boat and towed in the direction of the ship's drift, and if there is any wind it is best to lower all the sails down. An outrigger, fitted with a block, should be fixed in the weather quarter, through which the line ought to be rove and bent to the instrument, when it ought to be lowered until it is a fathom below the surface, and then let go. The instruments and lines may, however, be made for different depths, and used accordingly. For the North Sea I would recommend one of fifty pounds."

The cast iron sinker of the one actually used by Captain Ross was a long, hollow, parallelopiped, weighing one hundred weight.

About the same time as Sir John Ross was prosecuting his voyages on behalf of the Government, Scoresby, in pursuit of his trade as a whaler, was collecting most valuable information. Of all the navigators who have combined with the due discharge of their duties as sailors the scientific investigation of the conditions of the ocean, the younger Scoresby is certainly the one most imbued with the spirit of the philosopher. The problems to be solved seem to present themselves at once to his mind divested of all irrelevant matter, and he attacks them directly and successfully. In sounding at great depths, for instance, he at once recognizes that when the ordinary deep sea line and lead are used, the increasing weight of line, in proportion as more of it is required, renders less certain the determination of the moment when bottom is reached. He determines the density of the water with a thermometer with large bulb and narrow stem, and he gives a table for correcting observed specific gravities for temperature, which shows that he knew that sea water did not attain a maximum of density at the same temperature as distilled water. The following passage from his "Arctic Voyage" will show how thoroughly he knew the nature of the work which he had taken up:

"The difficulty of getting satisfactory soundings at great depths arises, principally, from the uncertain intimation given when the lead strikes the bottom. This uncertainty is increased by using a thick line; for if a lead of a hundred pounds were used, the rope attached to it would require to be so thick that, at the depth of six or eight hundred fathoms, the weight of the line, even in water, would be so many times greater than that of the lead, that scarcely any effect could be observed when it should reach the bottom. Hence, I always prefer a light lead and a very small line. With a lead of 20 pounds I have sounded in above 1,000 fathoms, and felt assured that if it had struck the bottom I should have observed it, for the whole of the line in use was not above twice as heavy as the lead; so that the diminution of one-third of the weight would have been very observable. But with a heavy lead and thick line, where the strength of several men is requisite to haul it up, there can be no evidence, without the test of weighing, of any trifling alteration in the strain of weight. Hence, if the lead is found to have been at the bottom, there can be no assurance that a quantity of the line, as well as the lead, has not also been on the ground. To a 28 lb. or 28 lb. lead I generally attach 200 or 300 fathoms of common log line, where there is no valuable apparatus along with it, and to this a small lead line, and finish with a deep sea line, thus increasing the line in thickness with the increase of weight to be supported; and having the whole of such a weight that the line can be held in the hand, and the least stoppage made perceptible."

After showing how, from observation of the whale fishing, he had often been able to draw correct conclusions as to the depths of water, seeing the amount of line which they would take out when running perpendicularly downwards, he relates the following story from the log-

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book of his father, who was also a whaler:

"At great depths, the effects of the pressure of the sea is not a little curious. My father met with the following singular instance, in the year 1749, which I have taken from his logbook. On the 31st of May, the chief mate of the "Henrietta," of Whitby, the ship my father then commanded, struck a whale, which 'ran' all the lines out of the boat before assistance arrived, and then dragged the boat under water, the men meanwhile escaping to a piece of ice. When the fish returned to the surface to 'blow' it was struck a second time, and soon afterwards killed. The moment it expired it began to sink, which, not being a usual circumstance, excited some surprise. My father, who was himself assisting at the capture, observing the circumstance, seized a grapnel, fastened a rope to it, threw it over the tail of the fish, and fortunately hooked it. It continued to sink, but the line being held fast in the boat, at length stopped it, though not until the 'strain' was such that the boat was in danger of sinking. The 'bight' or loop of a rope being then passed round the fish, and allowed to drop below it, inclosed the line belonging to the sunken boat, which was found to be the cause of the phenomenon observed. Immediately the harpoon slipped out of the whale, and was, with the line and boat attached to it, on the point of being lost, when it was luckily caught by the encompassing rope. The fish being then released from the weight of the line and boat, rose to the surface; and the strain was transferred to the boat connected with the disengaged harpoon. My father, imagining that the sunken boat was entangled among rocks at the bottom of the sea, and that the action of a current on the line produced the extraordinary stress, proceeded himself to assist in hauling up the boat. The strain upon the line he estimated at no less than three-fourths of a ton, the utmost power of twenty-five men being requisite to overcome the weight. The laborious operation of hauling the line in occupied several hours, the weight continuing nearly the same throughout. The sunken boat, which before the accident would have been buoyant when full of water, when it came to the surface required a boat at each end to keep it from sinking. When it was hoisted into the ship, the paint came off the wood in large sheets, and the planks, which were of wainscot, were as completely soaked in every pore as if they had lain at the bottom of the sea since the Flood. A wooden apparatus that accompanied the boat in its progress through the deep, consisting chiefly of a piece of thick deal, about fifteen inches square, happened to fall overboard, and though it originally consisted of the lightest fir, sunk in the water like a stone. The boat was rendered useless; even the wood of which it was built, on being offered to the cook as fuel, was tried and rejected as incombustible."

The incident is exceedingly interesting, as being, perhaps, the first occasion on which the effect of the enormous pressure produced by a column of water was directly observed. It will be observed that the wood, though painted, got completely water-logged, while the whale, which must have penetrated to nearly the same depths, retained its buoyancy.

The plan introduced by the Americans, of using fine twine and a heavy weight, sacrificing both at every sounding, was one which, with a little elaboration, could have been made to give very accurate measurements of depth. And, indeed, when it was found that ordinary observation or feeling did not suffice to indicate when the shot had reached the bottom, the practice of observing the rate at which successive equal lengths of the line passed out, which has since been so useful, was introduced. It is worthy of remark that, at this early date (about 1850) iron wire was used instead of twine, by Lieutenant Walsh, of the U. S. schooner "Taney."

When telegraphic enterprise began to develop itself, deep-sea sounding became of great practical importance, and, since the date of the first Atlantic cable, it has been carried on both by governments and commercial companies, with all the energy produced by prospective money making. For the telegraphic engineer, however, it was not enough to know the depth of the water; it was of almost equal importance for him to know the nature of the ground on which his cable was to lie. The invention, in 1854, by passed Midshipman Brooke, of the U. S.

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Navy, of a contrivance to detach the weight used to carry down the sounding line, while it enabled a specimen of the bottom to be brought up, was of great importance in rendering easier and more accurate the survey of the ocean bed. Brooke's sounding apparatus consisted of a cannon ball, with a hole drilled through it. Through this hole passed a straight rod, fitted at its upper end with peculiar disengaging hooks. The weight was slung to these hooks by means of a wire, which passed from a ring, which was slipped over the rod under the weight, up on each side of the cannon ball to the hooks. The sounding line was attached to eyes in these hooks, and as long as the lower end of this rod was not resting on anything, the weight was kept securely in its place, and available for taking out the sounding line. As soon, however, as bottom was reached, and this rod came to be supported on its lower end, the hooks at the upper end fell forward, and allowed the wire to disengage itself. The weight was thus released, and, on the line being pulled up, the rod came away through the perforation of the shot, and brought with it specimens of the mud in small quill tubes fitted in a recess in the lower end of the rod. The principal object which Brooke had in view was to disengage his weight, and his contrivance for doing so is excellent, the moment the end of the rod touches bottom, the weight slips off. In order, however, to gain the greatest possible amount of information from a deep-sea sounding, it is advisable to arrange so that the tube, which is now used in similar machines instead of a rod, should penetrate the ground as far as possible. This is attained by so arranging the apparatus that the weight does not detach at the moment of striking bottom, but only when hauling in is begun. This condition is fulfilled in the instrument used in H. M. S. "Bulldog," by Sir Leopold M'Clintock, in the year 1860. It is a modification of Sir John Ross's "deep-sea clamm," in which the weight presses the clamm into the ground, until, on pulling in the line, it is thrown off and left at the bottom. This instrument brings up a specimen of what is at the surface of the ground, but does not give a sample of what is below.

The "Fitzgerald" sounding machine was used in the expedition in H.M.S. "Lightning," in the summer of 1868, when it gave satisfaction. It was tried on board the U.S.S. "Tuscarora," and Commodore Belknap reports unfavorably of it. From its irregular form, it offers considerable resistance during descent, and in coming up gets the line full of kinks.

At the latter end of 1868, Captain Shortland was ordered to make soundings between Bombay and Aden, and for this purpose he devised and constructed on board his ship, the "Hydra," a modification of Brooke's apparatus, which gave great satisfaction, and was afterwards used in the "Porcupine" and the "Challenger." The general arrangement is the same as in Brooke's apparatus; instead, however, of a rod, he has a brass tube, which passes through the center of the weight, which consists of one or more cylinders of cast iron. These weights are slung by a wire to a shallow hook, on the upper part of the rod, which surrounds the brass tube. The lower end of the brass tube carries a pair of buterfly valves, and in the middle of the tube are two conical valves opening upwards, between which a sample of the bottom water is secured, while a specimen of the mud is brought up in the lower segment of the tube. In later instruments, the tube was adapted only for the reception of the mud. When this instrument was used, the tube penetrated into the ground until the weights were supported on the bottom, when a steel spring at the upper end of the rod expanded, and threw the bight of the wire off the hook. The weights were thus released, and on hauling in the line, the tube alone was brought up. During the first year of the cruise of the "Challenger," this instrument was exclusively used, and it gave general satisfaction. The principal objection to it lay in the smallness of the samples of bottom which it brought up. This was due first to the narrowness of the tube, and also to the butterfly valves at the end. The object of these valves is to keep the samples from being washed out, but they also very materially obstruct the entrances. With a much larger tube, and a rightly ground valve at the top, better samples would have been obtained.

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After the first year of the cruise, the "Hydra" machine was replaced by the "Bailey." This was an apparatus very much on the same lines, but differing from the "Hydra," in the size of tube, and the method of disengaging. The tube, which was of iron, was 5 feet long by 2½ inches wide, and weighed alone 25 lbs. The hook which carried the wire and weights formed part of a separate brass piece, which telescoped into the iron tube the moment it touched bottom, thus throwing off the weights without utilizing them for pressing the tube further into the mud. The weight, however, of the tube alone was so considerable, that this was of little matter, and the "Bailey" usually brought up large samples of mud. It must, however, be remembered, that though the samples were large in quantity, they were principally from the superficial layer. In working with a tube of 2½ inches internal diameter, a substantial valve of some sort is necessary to prevent the samples falling out when the tube is being brought on board. Such a valve is always a great impediment to the entrance of the mud. It would, therefore, be of great importance to arrange the Bailey tube, so that the weight should be utilized in shoving it into the ground, and also that a greater length of it should protrude beyond the weight. In this way, samples of the mud below the superficial layer would be obtained, and the interest attaching to it is evident. Even with the "Bailey," as it is, we find in several places a red clay at the surface, with white mud below it.

In exploring the seas and lakes of the Highlands of Scotland, I have made extensive use of a form of sounding tube and lead, which I devised for the purpose, and which I have always found to act very well. Its construction is simple, being in effect nothing but a straight brass tube, of one inch diameter, carrying a brass shoulder about one foot from the lower end. A cylindrical leaden sinker of suitable weight is slipped over the upper end, and rests on the shoulder. This line is made fast to a metal eye at the top, and the part of the tube below the shoulder can be unscrewed, and the mud which has been brought up in it squeezed out by a plunger. I have tubes of various lengths, with sinkers of various weights, for work at different depths, and under different conditions. For work in inland lakes it is necessary that every thing should be as light as possible, in order to be suitable for land transport. I use a tube and sinker, weighing in all three pounds; while at sea, with the steam winch available, the sinker weighs generally 28 lbs. Where the bottom is soft mud, these tubes bury themselves in it, and bring up very considerable samples. The samples are also very satisfactory when the bottom is clay; when, however, the bottom is hard sand, or similarly resisting material, the tube impinges suddenly on it, and does not penetrate as deeply as might be wished. The effect is very much as if an attempt were to be made to make a spade penetrate the ground by a sudden blow, instead of a persistent shove. I have designed an arrangement which will enable the tube to exercise a gradual pressure on the bottom, and so to penetrate muds or sands, which offer considerable resistance. Instead of the weight resting on a metal shoulder, rigidly attached to the tube, I suspend it by strong india-rubber cords, from hooks near the top of the tube. When the tube strikes the bottom, the weight delivers its blow gradually through the stretching of the india rubber. I have had a tube of this kind constructed five feet long, and with a valve at the top. This valve at the top is to prevent the contents of the tube falling out by their own weight, when the apparatus has been taken out of the water, and is being brought on board. These tubes bring up samples of often very coarse sand, and Captain Tizard, who tried one last year in the surveying vessel "Knight Errant," found that in *globigerina* ooze it was washed out on the way out. I feel sure that, with the india rubber slings, the tube would penetrate through the layer of comparatively unbroken *foraminifera* on the surface, and plug itself at the bottom with the more finely comminuted and clayey substance which is usually found below. Where the object is to make soundings rapidly, and to get a small sample of the mud on the surface of the bottom (as in sounding for telegraph cables), a lead with a blunt end is used. This penetrates only a small way into the mud, and is easily

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drawn out, bringing a sufficient sample in the axial tube. Mr. Gray, of the Silvertown Telegraph Works Company, showed me the sinkers used on board their ships. They weigh thirty pounds, and at the bottom of the tube is a very simple and ingenious valve, made of india rubber, which is pressed against the side of tube by the lead, while sinking, and expands, and closes the orifice sufficiently to prevent the sample being washed out on coming up.

I now proceed to consider the precautions to be observed in the actual use of these instruments.

On stopping the ship, "to make a station," the first operation is to determine the depth. For this purpose the ship, under steam, is brought head, or in some cases stern, to wind, and kept as nearly as possible stationary while the sounding is being effected. The method of sounding in deep water is essentially the same whether hemp line or wire is used. In both cases, it is necessary to load the end of the line with such a weight that, in the deepest water which may reasonably be expected, the velocity of descent shall not be diminished to an excessive extent by the friction of the increasing length of line in passing through the water. Twenty years before the "Challenger" sailed, wire had been used on isolated occasions by the Americans, but it was not until Sir William Thomson took it up, and, with characteristic energy, worked it out into a practical method, that it became really available. When the "Challenger" was fitted out, it was decided, and, I think, wisely decided, to use hemp line, which had already yielded valuable results, and the working of which, even at the greatest depths, was familiar to her captain and officers. During the three and a-half years of her expedition, the extension of telegraphic enterprise rendered rapid deep-sea sounding a necessity, and, in consequence, developed both the apparatus and the art. Now-a-days, our sailors are almost as familiar with the handling of wire as with that of rope, and no similar expedition would now start without being furnished with apparatus for using wire in deep sounding. At the same time, it would be equally improper to start without a sufficient supply of good hemp line, and the apparatus for working it. For we should never allow our affection for what is novel to blind us to the advantages of what is older fashioned. For many purposes wire must supersede hemp, because it does the work better and more expeditiously, but there are other departments of the work of deep-sea investigation which are better done with hemp. The great advantage of wire above hemp is that, for the same tensile strength, we have a line which passes through the water without developing any serious retarding force due to friction, whereas, with hemp line, the retardation so produced is very great. The saving in time and labor, due to the absence of this frictional retardation, is so great that there can be no question of choice between wire and hemp when it is required to sound in deep ocean water. To take an example, in water of 1,500 fathoms, a three-hundred-weight sinker, with the best hemp-sounding line, takes twenty minutes to reach the bottom; with wire, and a thirty-pound sinker, the sounding is completed in from twenty-five to thirty minutes.

Although, however, it is thus incomparably superior to hemp for deep sounding, it has disadvantages from which the hemp is free. Its greatest drawback springs from its liability to break. A hemp line may be bent and twisted in any way we please, without its strength being in any way affected; not so, however, with wire. During its whole lifetime it must never suffer a sharp bend, or twist, or nick; if it does, its strength is gone; and if the damaged part is not cut out an accident is sure to happen. Again, Sir William Thomson has always advocated the use of naked steel wire, which rusts easily when moistened with salt water. In order to preserve it, the wire, along with the reel, has to be kept in a tank of water rendered alkaline with soda or lime. This is an inconvenience; but my own experience leads me to the conclusion that there is no reason why galvanized steel wire should not be used, and I find that it keeps perfectly well without any preservative. The objection usually raised to galvanized wire is, that the process of galvanizing weakens it. This difficulty I got over by taking No. 20 galvanized instead of No. 22 naked, as recommended by Sir William Thomson. Where steam power is not

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available for heaving up, the wire possesses a very great advantage, for it can be easily worked, even at very great depths, by hand. The U. S. ship "Tuscarora," which, in 1874, sounded out the route from San Francisco to Japan, and, in doing so, surveyed the deepest water in the world, did all her sounding by hand. As an instance of what can be done, I will quote from Captain Belknap's report, the work done on the two days, January 17th and 18th. Six soundings were made, all in water over 4,000 fathoms in depth; forty-two observations of the temperature at depths below the surface and 1,200 fathoms were made, and the current was observed at 10, 20, 30, 50, 100 and 200 fathoms below the surface. One of the soundings, the depths being 4,356 fathoms, occupied two hours and twenty-seven minutes, the descent occupying fifty-three, and the reeling in ninety minutes.

With steam power at hand—and without it, it would be folly to attempt deep-sea work—hemp line becomes preferable to wire, where the other branches of deep-sea work are being carried out, such as serial temperature observations, and the collection of water samples from different depths.

Deep-sea thermometers which have been carefully compared with a standard, and which have been used in many soundings, are instruments of very great value, and if lost cannot be replaced by the purchase of new ones. Hence, in making such observations, the conditions which we have chiefly to keep in view is the safety of our thermometers, while, for the completeness of our work, it is important that the temperature should be observed at as many different depths as possible. Now, as the chance of the hemp breaking is very small when compared with the wire, it is permissible to risk a great number of thermometers on it than on a thin wire. Therefore, to get same number of observations with the wire would require the operations of sinking and heaving-in to be repeated a greater number of times than with the hemp, and as a thermometer must be allowed a certain time to take the temperature of the water, it will be seen that for such work the wire is in the end no more expeditious than the hemp, and the use of it is attended with considerable risk of the loss of valuable instruments. I am quite convinced from my own experience, that for all work in depths up to 500 or 600 fathoms, hemp is better for all purposes, because a sinker can be used, which will make it descend nearly as quick as wire, and, with a steam winch, it can be brought up at nearly the same rate.

The wire has, of course, the advantage, that it stows in much smaller space than ordinary sounding line.

Finally, and to answer the question which is often put me, whether wire or hemp should be used in a ship's outfit, I would say take both, as they are both useful in their proper places. For determinining the depth, use wire; for detail work, with the thermometers and water bottles, use hemp. In this way your sounding will be done expeditiously, and you will not lose your instruments.

With regard to dredging, which forms a very important department of deep-sea investigation, there can be no doubt of the great superiority of wire over hemp rope. The advantage in point of rapidity of work, and of stowage space, is much greater than in the case of sounding. Here, again, we are indebted for a scientific instrument to the enterprise of telegrapic engineers, for if it had not been a necessity for them, it is not likely that we should now have had the very beautiful flexible steel-wire hawsers which are to be found in nearly every ship.

Steel-wire rope was first used for deep-sea dredging by Professor Agassiz, in the winter 1877–78, and he has continued to use it with great success. His rope "was one and one-eighth inches in circumference, and was composed of six strands laid round a tarred hemp heart. Each of the six strands was composed of seven galvanized steel wires of No. 19 American (No. 20 Birmingham) gauge. The ultimate strength of the rope was 8,750 lbs.; weight per fathom 1.14 lb. in air, and, approximately, 1 lb. in sea water; price, eight cents per foot."

In the summer of 1878, I fitted the steam yacht "Mallard" with a steel-wire dredging rope, for work in depths up to 200 fathoms. It consisted of five strands, arranged around a center of cotton, and each strand consisted of

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seven steel wires (No. 24 B. W. G.) 0.023 inches in diameter. The diameter of this rope is 0.19 inches, and circumference 0.06 inches; its weight per fathom is 0.33 lb., and breaking strain 30 cwt. It was, unfortunately, not made of galvanized wire, and has now been in use for three seasons without being kept in any kind of preservative; and, although necessarily rusty, its worst fault is that, when in use, it is apt to stain the deck.

In deep water, Captain Sigsbee gives the following as safe work: Time per hundred fathoms, paying out and hauling back, three to five minutes, according to circumstances. He reports a good haul having been made in 800 fathoms in one hour and twenty minutes, including twenty-three minutes for dragging.

My object in furnishing myself with the wire rope was not to dredge, but to be able to anchor in the deepest water to be found on the west coast of Scotland, and thus facilitate the carrying out of physical and chemical observations on the water. In 1877, when I explored a large number of the Scottish lakes and sea lochs, I had found that, in a fresh-water lake, the vertical distribution of temperature is often very different in one place from what it is in another place not many hundred yards distant. The same was also found, though in less degree, in sea-water lakes. It became, therefore, of the utmost importance in investigating the conditions of temperature in the water, to be sure that the observations were really all made in one and the same place. It is impossible to keep a vessel stationary in one position by means of steam, unless, perhaps, in a land-locked bay, with a breeze blowing sufficiently strong to make the vessel drift faster than her lowest rate of steaming. It became, therefore, of the greatest importance to be able to anchor anywhere, and for this purpose the rope above described was furnished. In the season of 1878, I used a kedge anchor of ordinary form, and weighing 84 lbs. It was attached to the wire rope by means of about twelve fathoms of 2½ inch Manilla rope. Often a couple of furnace bars were strapped on to the Manilla at five and ten fathoms from the anchor, with a view to keep a curve on the line. This arrangement was found to work extremely well. Everything was prepared beforehand, and when the vessel was in position the anchor was let go, and the wire rope allowed to run rapidly off the reel, the strain on the break at the reel being carefully regulated by means of a spring balance, so that the moment the anchor touched the bottom, the reel stopped. The break was then secured at a known strain, such that as the vessel drifted she would take what rope was required. There was thus no paying down of slack line on the top of the anchor. When it was judged that enough rope had been given, the strain on the break was increased, which by gradually bringing the weight of the ship on the anchor, steadied it into the ground. When the anchor was found to be holding, the reel was secured in such a way that, if necessary, it could easily be cast loose, and the vessel being stationary, and at anchor, the work could proceed. It is of great importance that the wire rope should be held fast on board in such a way that it can be easily let go; for, if the anchor begins to drag, then the ship gathers way, and if now the anchor suddenly holds, and it is impossible to veer cable, a very excessive strain is put on the rope in order to stop the ship's way in a very short distance. If, however, the reel can be released, then, by careful working of the break, the anchor can again be steadied into the ground, and the ship stopped without any undue strain being applied to the rope. The rope passes out over the bow of the vessel through a metal block on one of the iron davits used for "catting" the anchor. From this block it is led through another block, which is attached to a spring balance, to the drum of the steam winch. The angle made by the line between the winch and the outer block is always the same; consequently, the strain shown by the spring balance is always the same fraction of the total strain on the line. This fraction, in our particular case, is as nearly as possible one-third. In heaving up the anchor, it is only necessary to watch the spring balance in order not to over strain the line. The moment which requires very careful attention is when the anchor is being started out of stiff ground. By careful handling of the winch, the strain is kept steady until the

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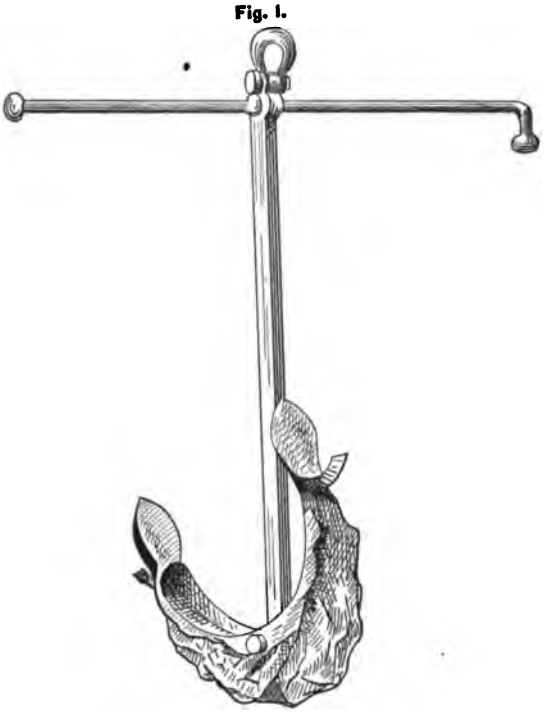
anchor comes away, which is shown by the index of the balance jumping suddenly back when the cable is rapidly wound in. It is taken from the winch by the reel, which is wound up by hand. In deep water, the bottom is generally covered by a surface layer of very soft mud, having no holding power; it is necessary, therefore, to allow the anchor to sink by its own weight through this before any great strain is brought on it. During the summer of 1878, the anchor used as described brought up so many valuable specimens of this kind, especially of those existing below the surface layer, that I determined before the next season to provide myself with an anchor which should not only hold the ship, but retain the mud into which it had fixed itself. It is essentially a Trotman's anchor, with an open frame, instead of a solid bar connecting the two palms. To this frame is laced a stout canvas bag, into which any mud sticking to the palm, at the moment of breaking out of ground, falls (Fig. 1). This has proved itself a most successful instrument for exploring the bottom of the seas, especially where the object is to collect the mud itself, rather than the things that live on its surface. Also, as an anchor pure and simple it is most efficient, being constantly used as an ordinary kedge anchor.

The economy in stowage, caused by using wire rope, such as I have described, will be very apparent if we consider the amount of it which can be wound on a reel of moderate size. Let the diameter of the core of the reel be 18 inches, and the diameter of the rope 0.2 inch, then, if carefully and tightly wound on such, a reel will hold sixty turns per foot of length. If the cheeks of the reel be constructed so that rope may be wound on it until the outside diameter of the coil is 28 inches, then the average diameter of one turn of wire rope is 23 inches, and the average circumference one fathom, and the number of turns counted in the direction of a radius would be fifty. We should then have, on a reel 1 foot long by 2 feet 4 inches in diameter, 3,000 fathoms of wire-dredging rope. If the diameter of the cheeks were made, say, 2 feet 8 inches, then 3,000 fathoms would

Fig. 1.



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be easily accommodated, even without great care in winding. The whole weight of the line would be 1,000 lbs. It would, however, be advisable, if dredging were to be attempted at such depths, to graduate the size of the line; for it is quite evident that, with 3,000 fathoms of it out, the part at the surface of the water has to sustain all the strain due to the dragging and the weight of the line, or 9 cwt. weight. As the breaking strain when new is 30 cwt. weight, there would be an insufficient margin. Doubts have often been thrown on the trustworthiness of deep soundings, as carried out in the ordinary and simplest way, using a hemp line and heavy sinker, and keeping the ship as stationary as possible. The sources of error most frequently are, or at least were, the compressibility of water and the existence of currents, principally undercurrents.

When a liquid suffers compression, its density is increased; consequently, it was asserted, that at some very great pressure, the density of water will become equal to that of lead, and our sinkers, instead of sinking, will float. Were water compressible in the degree that air is compressible, then the density of water might increase at such a rate as to make lead float, supposing the lead to remain meantime uncompressed; but, whereas the density of air is doubled by raising the pressure worked on it from that of one atmosphere, or 30 inches of mercury, to that of two atmospheres, or 60 inches of mercury, the density of water is only increased by one-twenty thousandth. Now, supposing that the compressibility remains the same at high pressures as at low, it would require a pressure of twenty thousand atmospheres to raise the desity of water from one to two, and more than two hundred thousand atmospheres to raise it to the density of lead. One hundred fathoms of sea water exert a pressure of about eighteen atmospheres; and we may assert with perfect confidence, that the deepest water in the globe is under five thousand fathoms in depth; therefore, even at the greatest possible depths, the density of the water could not be raised by as much as one-twentieth by pressure alone, and the sinking power of lead, which is itself rendered denser by pressure, could not be appreciably affected. This objection to the validity of deep soundings would not have been worth referring to, were it not that it has been admitted by persons of high authority, and has, by consequence, influenced a large number of persons whose convictions are determined by authority alone. Admiral FitzRoy, for instance, in an appendix to his volume on the voyage of the "Beagle," says: "The depth to which bodies would sink in an ocean several miles deep has not been proved, and there is reason to think that it is much less than people generally imagine," &c. Scoresby, however, twenty years earlier, with his usual acumen, was able to attach its proper value to objections on this ground. He says: "In sounding at great depths, where the pressure of the water becomes equal to, perhaps, several hundreds weight on every square inch of surface, some persons have imagined that even lead cannot sink, but will be suspended midway in the sea. I have conversed, indeed, with very intelligent persons, who could not be persuaded that any dependence could be placed on soundings obtained at a depth exceeding 300 fathoms. Were water a compressible substance, like air, it would be possible that, under a certain pressure, it might become as heavy as lead, so that lead, or any other ponderous body, could only sink to a certain depth; but water being incompressible, or nearly so, it is clear, however great the pressure may be, that it must be the same downward as upward, on any body suspended; consequently, bodies specifically heavier will continue to gravitate downward, whatever be the depth or the weight of the column of water above them."

The other objection to the trustworthiness of deep soundings is a real one, though it is often exaggerated. There is no doubt whatever about the existence of surface currents of great extent and velocity in the midst of the ocean; they are observed and measured every day, as they form a very important factor in the navigator's daily reckoning. Before deep-sea investigation had received the development which it has now, it was quite uncertain whether these currents (the Gulf stream, or the equatorial current, for instance) were confined to the superficial layer of water, or extended in all their force to the bottom. No sooner,

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however, had soundings been attempted in them, than it was found that they were comparatively superficial; but, notwithstanding that they were on the surface, and, therefore, immediately under observation, they caused so much deviation in the direction of the sounding line, and such uncertainty in the stationariness of the ship, that soundings so obtained were always considered uncertain. It was then said, if we have these surface currents running from one part of the ocean to another, we must have return currents of some kind, and it is likely that these will be for the most part undercurrents; if, now, a surface current, which you have immediately under your eye, gives you so much trouble, how much more will this be the case with an undercurrent of whose strength, and direction, and depth, you are ignorant?

It must be admitted that when we do meet with currents of the kind imagined, soundings taken in them, whether with wire or hemp line, are very much less to be relied on than those taken in manifestly quiet waters; but, on the other hand, the existence and extent of undercurrents has been very much exaggerated. By far the larger portion of the ocean is, for sounding purposes, practically still water. The surface currents of any importance are easily recognized, and so also are the undercurrents. Just as a physician can, by bringing his experience to bear on the sounds transmitted to him through the stethoscope, divine what is taking place inside the body of his patient, so the experienced seaman can, by observing the behavior of his sounding line, form a fair diagnosis of what is taking place in the depths of the sea. When the sinker passes into a belt of undercurrent, the fact is very soon apparent, and calls for the greatest care in the maneuvering of the ship. Even with the greatest possible care, however, soundings taken under such circumstances, would always be considered to be of doubtful value. If no bottom is brought up, they should be looked on as very doubtful, and even discarded; if bottom is brought up, then we know that the depth is not greater than the line used, and a correction, suggested by observation and experience, may be applied, which will bring the depth very near the truth. Although, as we have said, by far the greater part of the ocean may be looked on as still water, and, therefore, favorable for investigation with the sounding line, it is, nevertheless, of great importance to obtain accurate measurements of the depth of water under well-marked currents.

It is evident that this cannot be satisfactorily done by the sounding line alone, and it early occurred to those who thought on the subject that the method which promised most success was that which should give the depth in terms of the height of the column of water; in other words, the barometrical measurement of altitudes was extended from the land to the sea. Many and various instruments have been suggested and used for the purpose. They are all constructed with a view to record the amount of compression produced on a given mass of a certain elastic substance. From the known law regulating the variation in volume of the substance with variation in the pressure, the maximum pressure to which the instrument has been exposed can be deduced, and from the known density of the water, the height of the column of it, which would produce this pressure, can be calculated, and this height is the depth to which the instrument has been sunk. Many different substances have been used for this purpose, and foremost amongst them air, on account of its great compressibility. For deep work, however, this was quickly found to be a great disadvantage, so great, in fact, that it has never been satisfactorily used at considerable depths.

The compressibility of water was discovered in 1762 by John Canton, and, fifty years later, in extending Canton's original observation to higher pressures, Perkins sank his instruments to various depths in the North Atlantic Ocean, on a voyage from America to this country. These instruments were glass tubes, sealed at one end, filled with water, and inverted in a cup of mercury. In the tube was a steel index which rose with the mercury, and was retained by a spring at the highest point reached. It could be drawn down again, and the instrument so reset by means of a magnet applied to the outside of the tube. Encouraged by the results so obtained, Perkins constructed a hydraulic apparatus, in which he could expose his in-

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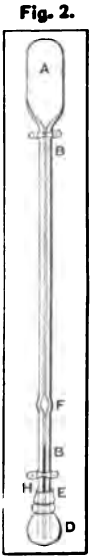
struments to enormous pressures, which he measured directly by the weight which a plunger could support. He, at the same time, suggested the use of these instruments, or piezometers, for determining great depths. The same suggestion was repeated in 1848 by Aimé, to whom we owe many valuable researches in the Mediterranean, and by the United States Coast Survey a few years after. The same idea occurred to myself in view of my appointment to the "Challenger," and, indeed, it is one of those ideas which necessarily suggest themselves to any one who seriously reflects on the subject. The form of piezometer which seemed to me to be best suited for the purpose was, essentially, that of Perkins, with certain convenient practical modifications. For filling the instruments, I

Fig. 2.



used generally distilled water, and sometimes sea water, or an equivalent salt solution. The bulb and stem of the instrument were so proportioned that, for a depth of one hundred fathoms, the apparent contraction of the water occupied a length of ten millimeters. Some, however, were more, and others less, delicate than these. My object in using water or weak salt solution, as the elastic material, was that, as the temperature of maximum density of these liquids was not far removed from that obtaining in the great mass of deep oceanic water, a considerable inaccuracy in the determination of the temperature of the water would make no sensible difference in the apparent volume of the liquid, and therefore would not sensibly vitiate the depth determination so obtained. Unfortunately, the vicinity of the temperature of maximum density exercises an influence on the compressibility, which counterbalances its advantages from a thermal point of view. A strong salt solution would probably be better. Were the temperature at the bottom of the ocean subject to great variations, the use of distilled water would be quite inadmissible, but over large areas, its variations are confined to fractions of a degree. Hence, the irregularities in the depths given by the piezometer, and due to this cause, are small, though not absolutely to be neglected. I am engaged, at present, in experiments to determine what is the best liquid to use for this purpose.

Another method of measuring the pressure, and through it the depth of the sea, is by means of an instrument much resembling, in principle, the aneroid barometer. Its simplest form is that usually given to a mercurial thermometer. When the pressure on the outside of the instrument is increased, the bulb experiences a tendency to collapse. It yields wherever its walls are weakest, and if the pressure is kept within the necessary bounds, a flattening is produced, which reduces the internal volume of the bulb, and forces the mercury into the stem; if an index is fitted in the steam, its position will indicate that of the extremity of the mercury at the moment of greatest compression. Inventions on this principle have been patented over anp over again in the course of the last twenty or thirty years.

The chief objection to the instrument is that, in practice, it is always filled with mercury. Over the greater part of the ocean the temperature of the water falls as the depth increases. Hence, the mercury will be continually retreating, owing to its contraction due to fall of temperature, while it is being pushed forward by the mechanical collapse of the bulb. Until these two effects compensate each other, there can be no movement of the index, and, therefore, no indication of the depth. In water of tolerably uniform

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temperature, as in Polar regions, it ought to do well. Two instruments of this kind were sent to the "Challenger" by Mr. Casella, but they only reached her at the last port before her return to England. They were only used twice, and did not on those occasions give satisfactory results. Sir William Thomson has, within the last year, patented an instrument on the same principle, where the collapsible envelope is a very flat brass tube.

Very analogous to sounding in a current is the operation of sounding from a vessel in motion. We have already described the ordinary operation of heaving the hand lead, by means of which depths up to twelve or fifteen fathoms can be correctly observed under ordinary circumstances. In deeper water, however, and with vessels running at the high speed now common amongst mail steamers, a self-adjusting apparatus is an essential. Up to within the last few years, the commonest form of apparatus of the kind was Massey's sounding machine. In sinking, the friction of the passing water caused a screw fan to rotate, and the number of its rotations was recorded on dials in much the same way as the distance run by a ship is recorded by Massey's patent log. The form of this instrument, requiring, as it does, a system of multiplying wheels, causes it to offer considerable resistance when being hauled on board again; it is, therefore, not suitable, except for vessels going at a moderate speed. Further, if we look to the principle of the instrument, we see that what it in fact registers is the distance traveled by the instrument between the surface and the bottom. If it has been allowed to sink freely, then this distance will be equal to the depth of the water. But if, while sinking, it were exposed to a certain amount of drag, through strain on the sounding line, it would tend to sink sideways, which would put the screw fan to a disadvantage, and vitiate the determination of depth. Practically, this objection has little force, because, in a ship where it is thought proper to execute soundings of the kind, there will be no difficulty in seeing that the sounding line runs out freely.

In arranging for taking soundings from quickly-moving ships, it is important to have not only an instrument which will be dependent only on the true depth of the water for its indications, but also such mechanical appliances as will enable the operation to be carried out safely and expeditiously. To Sir William Thomson is due the credit of having furnished the practical solution of this as of many other problems. His original apparatus for registering the depths was a glass tube, sealed at one end, and coated internally with a chemical preparation (chromate of silver) the color of which was changed by the action of sea water. As the tube, with its included air, sank, the volume of the air diminished, and the sea water penetrated further and further into the tube, until the bottom was reached. On rising to the surface again, the elasticity of the air reasserted itself, and eliminated the water which had entered. The height to which the water had risen was given by the extent to which the internal coating of the tube was altered. The indications of this instrument were always very good, and the practical objection to it lies in the fact that a tube only serves for one sounding, and that, therefore, a number of these have to be carried.

In June, 1879, I patented an instrument, in which the degree of compression to which an enclosed mass of air had been subjected, was measured by the water which had gained admittance to the instrument.

As I now use it, the instrument is represented in Fig. 3. It consists of a glass tube open at both ends, but capable of being closed by a stopper or other means. At some part of the tube a spout is introduced, and the tube is bent over through two right angles immediately above it. When the instrument is to be used, the end is closed, and the line let go; when bottom has been reached, it is brought up again, and we find that a certain amount of water has lodged in the lower part of the tube. It is evident that, as the instrument descends and the air in it is compressed, the water forces its way in through an orifice, and past the spout. This spout is so formed that it delivers the water against the walls of the tube, down which it runs, and collects at the bottom. When the motion of ascent begins, the air, by its elasticity, tends to recover its original volume, and expands in the direction of greatest free-

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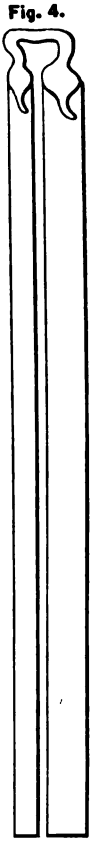
dom. Now, all the water which has entered has collected below the spout, consequently, in re-expanding, this water will be left undisturbed.

Fig. 3.

Fig. 4.



[☞] Assuming that the volume of the mass of air in the instrument varies inversely with the pressure to which it is subjected, we require, in order to be able to construct a scale for our instrument, and so to interpret its results, to know the total volume of the tube, the volume of the part which I call the vestibule, the dimensions and volume of the narrow tube, and of the wide one. Then, if V be the total volume of the tube, and v that of the vestibule, the amount of water which gains admittance when the pressure is raised from one to p atmosphere is:

$$v' = V - \frac{V}{p} v$$

$$= V \frac{p-1}{p} v$$

The methods by which a correct scale of fathoms can be easily applied to any instrument, and engraved either on the glass or on the metal case, or on both, are details of practical instrument making, which need not detain us.

Convenient dimensions for such a sounding instrument are: Total volume, twenty cubic centimeters; volume of vestibule, one cubic centimeter; length, forty to fifty centimeters. In hauling in the sounding line to a vessel under way, the machine comes to the surface a considerable distance astern of the ship, and then has to be towed through the wake, necessarily often dipping under the seas. Each dip which it makes constitutes an independent, though shallow, sounding, and the volume of the vestibule must be so proportioned to the volume of the instrument, that during such immersions no water shall pass the spout. When the instrument has been read, it is at once available for a fresh sounding; it is only necessary to remove the stopper, and let the water run out, and then replace the stopper again. Fig. 4 represents an instrument modified so that it can be used either for great or for small depths, according as either end is closed.*

* After the above was written, my attention was drawn by the Hydrogapher, Captain Evans, to an instrument identical in principle, though differing greatly in the details of construction, invented by Ericsson, and used successfully on board several of her Majesty's ships. It is described and figured in the *Nautical Magazine*, for 1836, and is reported on very favorably by Captain Bisson, of H.M.S. "Partridge," who was accompanied by the inventor, and they obtained successful soundings, in depths up to 80 fathoms, while going at a rate of six knots per hour. Along with the sounding machine, Ericsson brought on board a reel of wire for use, in place of sounding line. Captain Evans informed me that it had been constantly and successfully used under his own eyes, when engaged in the survey of the New Zealand coast, in H.M.S. "Acheron," in 1848, and that it had given great satisfaction.

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Sir William Thomson, in his latest specification of patent (February, 1880), recommends a group of three instruments, constructed somewhat on the lines of the above instrument, but composite and of sizes so apportioned that each shall be peculiarly sensitive at certain depths. He also recommends the use of the "elastic bottle gauge," alluded to above, combined with the triple air compression gauge, to give measurements of from 11 fathoms to 300 or 400 fathoms.

It may reasonably be doubted if it could ever be a matter of any importance to the practical mariner to obtain a positive sounding in 300 or 400 fathoms of water, either with or without stopping his ship, and to do so without checking her way would be a very serious undertaking. The weight and wire will not sink at a greater rate than about 100 fathoms per minute, or four minutes for four hundred fathoms, and during four minutes a ship going not more than 10 knots per hour will have advanced by 660 fathoms, so that, when bottom has been struck, there will be at least a thousand fathoms of wire, which, even with steam, could not be reeled in under a quarter of an hour.

The second and more mechanical part of the problem of deep sounding while under way, has been solved by Sir William in an elegant and practical form. His navigational wire sounding reel contains all that is requisite in the smallest possible compass. For my own work, I have made some slight modifications in the details. My reel consists of a solid hard wood core, thoroughly well painted and surrounded with a brass rim, in the hollow of which the wire is wound, and outside of which, on each side, is a break pulley. Pieces of soft hemp line are used for the breaks. The one which is used purely as a friction break is attached at one end to a spring balance, by means of which any definite pressure can be put on the reel. The other is used as a locking break, that is to say, it is taken one complete turn round this pulley in the direction in which it revolves when the wire is running out. When the weight has been observed to strike the bottom, this break is suddenly tightened, which instantly locks the reel when the handles are manned, the breaks thrown off and the wire wound in. I depart also from Sir William Thomson's practice in using galvanized in place of bright steel wire. In order to allow for any possible weakening effect of the galvanizing, I take the wire a size larger. In a small vessel like the "Mallard," I found it very inconvenient working the reel on the taffrail. I have it now well in board, and the wire leads out through a metal block, specially constructed for the purpose, and attached to the flag pole, as high up as a man can reach. In this way the work is carried out without difficulty. The galvanizing is a perfect protection to the wire, and all work with tanks and alkaline solutions is spared. Instead of having a heavy iron link at the end of the wire, I reeve the end of the wire through a piece of ¼-inch block tin gas pipe, about 15 inches long, and then bend it round and splice up the end of the wire so as to form an eye, to which the stray line for sinker and sounding machine can be attached.

In the U. S. Coast Survey Report for 1857, a very ingenious sounding instrument is described by a Mr. Hunt. The instrument consists of an air-tight bag, made of flexible material, with a long flexible tube attached to it. This bag, being filled with air, is sunk to the bottom (in a moderate depth of water) preferably by a heavy grating which surrounds and protects it. The other end of the flexible tube is connected with a Bourdon's pressure gauge in the ship or boat. If, now, this bag be towed over the bottom, and the pressure gauge observed on board, an exact profile of the bottom is given. I am not aware that this instrument has ever been much used for harbor surveying—for which it was intended—and it is not difficult to see where practical difficulties would be likely to occur; it has, however, been used with some success as a tide gauge, and it is clear that, for such a purpose, it possesses many advantages. The bag being securely anchored under water, it can be connected by a pipe of any length with the indicating gauge, or a recording instrument under cover.

For the purpose of observing the temperature of the waters below the surface in lakes and seas, two classes of thermometers have been used, namely, ordinary thermometers and self-registering

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ones.* The earliest observations were made with the ordinary thermometer, and it was used in one of two ways; either it was sunk itself to the desired depth, and was so enveloped and protected by badly conducting material, that in bringing it up again, through the layers of water of different temperature, it had not time to alter its own temperature; or a quantity of the water at the desired depth was enclosed in a bucket of suitable construction, and brought to the surface, and then immediately tested with the thermometer. Many very excellent and trustworthy observations exist, which have been made in one of these ways. Our first knowledge of the temperature of the deep water of fresh-water lakes was obtained from the observations of De Saussure, on the lakes of Switzerland, made with a thermometer, so padded and protected that it could be drawn up through 1,000 feet of water, of any temperature likely to be found in nature, without sensibly altering its temperature.

The self-acting bucket, or sea gauge, was used at an earlier date in the determination of the temperature of the deep water of the ocean. The accuracy of the results obtained by this method depends greatly on the skill of the observer. In the case of De Saussure, and of Fisher and Brunner, the results are clearly to be re lied on implicitly. In the experiments with the sea bucket, also, excellent results have been obtained. The results obtained by both methods of experimenting will be the more accurate the more uniform the temperature of the water. The temperature, especially of the bottom water, has also frequently been determined by bringing up a quantity of the mud, and taking its temperature when it arrives on board. This method also gives very satisfactory results when a considerable quantity of mud is at disposal.

Self-Registering Thermometers.—By far the greatest number of observations has been made with self-registering thermometers of one form or another. The first self-registering thermometer was made by Cavendish. He constructed both a maximum and minimum thermometer, and they were of the kind called by the French *a diversment*—out-flow thermometers. In fact, his maximum thermometer is in every particular identical with that known in France as Walferdin's; his minimum is on the same principle, but has a U-formed stem instead of a straight one. The disadvantages of this form of thermometer are two—namely, the indications are not continuous, but by jerks, depending on the size of the mercury drops, and they require to be constantly set, the maximum at a higher, and the minimum at a lower temperature than the one to be observed; they also require constant comparison with a standard. They are, therefore, not suitable for use where many observations have to be made expeditiously.

In the year 1782, Six published a description of the combined maximum and minimum thermometer which bears his name, and which has since continued to assert its place among meteorological instruments as perhaps the best self-registering thermometer. The instrument is too well known to require particular description. It may, however, be noted that Six himself did not use a hair for a spring to keep his indices from falling down, but a fine glass thread soldered to the top of the index, and sticking up in a direction very slightly inclined to that of the length of the index, so that it pressed gently against the sides of the tube. The advantage of the glass over the hair is that it does not lose its elasticity: but, on the other hand, the index takes up more room, and requires a thermometer with a larger stem.

Maximum and minimum thermometers, such as Cavendish's and Six's, when used for deep-sea exploration, show only the maximum and minimum temperatures to which they have been exposed in any one excursion, and a single observation with such a thermometer does not give us with certainty the temperature of the water at the depth to which it has been sunk. Hence, if we had a right to assume that the temperature of a sea or lake might vary in any conceivable way with the depth, these instruments would be valueless. We have, however, no right to make this assumption; we know, on the contrary, that in all seas whose surface is not exposed to a freezing temperature, the temperature of the water will, as a rule, diminish as the

* Proceedings of the Royal Society of Edinburg, 1880.

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depth increases, that, therefore, the minimum temperature, as shown by the self-registering thermometer, will, in fact be the temperature at the greatest depth attained by this thermometer. Hence, in such cases, this instrument is to be relied on, and more especially when series of temperatures are taken—that is, when the temperatures at different depths in the same locality are taken, so that the evidence of the decrease of temperature with the increase of depth is rendered as strong as possible. In order to render an account of the state of any lake or sea, as regards temperature, it is absolutely necessary to have such serial observations; hence, for such investigations, the maximum and minimum thermometer is not only trustworthy, but a most valuable and, indeed, indispensable instrument, for it has the great advantage that, as it is in the strictest sense self-registering, any number can be attached to the same line, and so, at one haul, the temperature can be observed at a number of different depths.

For isolated observations, the thermometers just described are not so satisfactory, and very great amount of ingenuity has been displayed in the invention of machines for registering the actual temperature of the water at any depth, independently of that of the water above it.

None of the instruments devised for this purpose have been strictly self-registering; they have all required some assistance from the observer, who, by various forms of mechanical appliance, brings about a catastrophe which leaves its mark on the condition of the instrument. It is obvious that any control which an observer may have over an instrument separated from him by, it may be, three or four miles of cord, is very limited, and is, in fact, confined to his ability to move it towards or from him. By a simple mechanical contrivance, this longitudinal motion may be made to produce one of rotation, and, in fact, the assistance afforded by the observer to the thermometer, to enable it to register its own temperature, consists in his turning it either upside down or through a whole circle when it has reached the desired depth. The first observer who made use of this device was Aimé. His working arrangement is described in "Ann. Chim. Phys.," 1843 [3], vii., p. 497. It is worked by a weight, which is allowed to slip down the line, and which then sets free the apparatus.

His *thermometre a bascule*, along with a number of ingenious modifications of existing forms, is described in the same journal, 1845 [3], xv. p. 5. It was unfortunately only after he was obliged to leave the Mediterranean, which had been the scene of his labors, that he invented the very elegant combination of thermometers by which he was enabled to ascertain the temperature at any depth, no matter what the intervening distribution might be. It is described in the memoir just cited. It consists of two outflow thermometers, so constructed that one of them registers the sum of the rises of temperature, and the other the sum of the falls of temperature, to which it is exposed in any excursion. When they have reached the required depth, they are inverted, and on their way back to the surface they register, as above described, the rises and falls of temperature to which they are exposed. If r be the sum of the rises of temperature, and f the sum of the falls, s the temperature at the depth where they were inverted will be $a=s+r-f$.

If they are allowed to register on the way down, and then inverted at the greatest depth, so as not to register on the way up, the effect will be precisely the same, though the functions of the thermometers will be reversed.

Beautiful and ingenious as Aimé's thermometers are, they have the disadvantages common to all outflow thermometers; they are neither simple enough nor handy enough for work involving many observations. The inverting thermometer, patented by Messrs. Negretti and Zambra, satisfies the conditions required of a thermometer for isolated observations as completely as can be hoped for. It is a mercurial thermometer; the bore of the stem is contracted to the smallest possible diameter at a point about an ich from the neck of the bulb. As long as the thermometer is standing vertically, stem uppermost, the mercury is continuous in stem and bulb; but if it be inverted, the mercury parts at the contraction, the portion in the stem falling down into the point. The stem is graduated from the point

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towards the bulb, and the temperature, at the moment of inversion, is read off by the height of the mercury in the end of the stem. This thermometer exists in two varieties, the one with a U-formed stem, which requires to be turned completely round. The turning arrangement for the latter instrument is a somewhat elaborate and expensive instrument, but it answers its purpose. The inverting arrangement, supplied with the half-turn thermometer, is somewhat clumsy and unsatisfactory, The half-turn instrument, when fitted with a suitable investing arrangement, is to be preferred to the others in all work at moderate depths.

Sources of Error in the Indications of various Thermometers.—When an ordinary thermometer, protected by badly-conducting envelopes, is used, it is obviously exposed to alteration of temperature by being pulled through warmer or colder water on its way to the surface. Whether any sensible error is likely to result from this cause, must be determined in each particular case by experience. The more perfectly it resists change of temperature, the longer it will take to assume the temperature of the water. De Saussure left his thermometer down for twelve or fourteen hours for each observation, so that this method is now seldom used. Similarly, also, the method which depends on bringing up a sample of water in a vessel fitted for the purpose, and taking its temperature with an ordinary thermometer, when it reaches the surface, has been discontinued; for although it does not take more time than would be necessary for sending down a thermometer and bringing it up, it is impossible to bring up water from great depths in warm climates without sensible change of temperature.

In the case of outflow thermometers, the delicacy of the instrument is limited by the size of the mercury drops. In the inverting thermometers of Negretti and Zambra an error may arise from the difference of volume of the mercury in the stem, at the temperature at which it was inverted and at that at which it is read. In an extreme case this may amount to as much as O. 4° F.; it can, however, be allowed for.

In Six's instrument there is a possible error from looseness of the indices, in consequence of which they are apt to be shaken out of their places by any jarring of the line. Errors from this source can be avoided to a great extent by attaching the thermometer to the line, by means of an elastic or india-rubber tube

All the self-registering instruments are liable to error from the effects of pressure. The pressure inside a thermometer is never greater than that of the atmosphere when it is sealed up. It may, however, be exposed outside to a pressure of 500 to 600 atmospheres. The effect of this difference of pressure on the outside and inside of the glass envelope is to make it tend to collapse. The bulb of the thermometer is squeezed, and its volume, in consequence, diminished. The liquid which it contains is thereby forced into the stem, and its apparent volume is greater than it would have been, had there been no excess of pressure on the outside of the instrument. The temperature of the instrument is measured by the apparent volume of the liquid which it contains; hence the effect of pressure is to raise the observed temperature above the true temperature. Parrot and Lenz, in 1832, made a series of experiments on the effect of pressure on thermometers. They experimented at pressures up to 100 atmospheres, and observed differences between the apparent and the true temperatures of as much as 20° C. They found that for the same instrument the compression was simply proportional to the pressure. They used a thermometer as a manometer. After this date it was usual to attempt some kind of protection for self-registering thermometers.

Those with straight stems, such as Walferdin's minimum, were sealed up in glass tubes, and so completely protected. Those whose stems were bent, had to be enclosed in metal cases closed with a screw. This form of protection never answered well, as it was impossible to screw on the cover so tight that the water, under the great pressures met with at considerable depth, would not find its way in. In order not to have to abandon the use of thermometers of the convenient form of Six's, the device of protecting the bulb only was hit upon, and it appears that the first thermometer of this kind was used by Captain Pullen, on board H.M.S. "Cyclops." The effect

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of pressure on the stem is quite insignificant, and under ordinary circumstances, insensible. For, in nearly all seas where the surface temperature is over 40° Fahr., the temperature of the water diminished as the depth increases, and, therefore, it is the minimum leg which is used, and the effective part of it is that filled with spirit, which may have a length of, at most, three inches. The effect of pressure in diminishing the volume of a short piece of thermometer tubing must certainly be very small, but its actual value can only be determined by removing the bulb, and taking the piece of the stem between the mercury and the neck of the bulb as the bulb of a new thermometer, and determining experimentally the effect of pressure on it. An approximation to the effect may be made by exposing the thermometer to various high pressures, at known temperatures, and observing the rise of the maximum index, then removing the bulb, and calibriating the stem. Knowing, then, the ratio of the volume of this part of the minimum leg, filled with spirit to the whole volume, from the bulb to the maximum index, it may be assumed that the compression will be in the same ratio. And this value will probably be greater than the real one, for the compression of the water produces of itself a certain rise of temperature, and, consequently, rises the maximum index. This can, however, be estimated, either by a comparison with a completely protected thermometer, or by bringing the minimum index also home on the mercury before raising the pressure. If, then, there has been a rise of temperature caused by compression, there will be a corresponding lowering of temperature on relieving the pressure. If the compression apparatus be allowed to stand after the pressure is up, until it has dissipated the heat evolved by the compression, the relief of pressure will cause a corresponding absorption of heat, which will show itself in the position of the minimum index. Some experiments which I have made in this direction show a lowering of temperature of 0.3° Fahr., for the relief of a pressure of 2¼ tons per square inch, the whole rise of the maximum index having been 1.8° Fahr. We may, I think, be quite certain that when the minimum leg is the one used, and the temperature low, the error caused by the effect of pressure on the stem is inappreciable. Cavendish, who invented the self-registering thermometer, foresaw also the most important of the uses to which it could be applied. Thus he suggests that the higher regions of the atmosphere might be investigated by attaching it to a kite—balloons not having been invented. With regard to deep sea explorations, he says:

"If instruments of the nature above described were to be used for finding the temper of the sea at great depths, some alteration would be necessary in the construction of them, principally on account of the great pressure of the water, the ill effect of which can, I believe, be prevented no other way than by leaving the tube open."

This was written in 1757, and it was not till 1762, as already stated, that Canton proved that liquids are compressible. Cavendish, therefore, hoped that as the pressure would not produce distortion of the glass when the tube was open, it would have no visible effect on the apparent volume of the liquid. The device of leaving his thermometer open at the end was adopted by Aimé in some of his experiments, the effect of pressure on the apparent volume of the liquid being determined independently, and a correction applied accordingly. I devised and constructed a mercurial thermometer, or piezometer (Fig. 5) on the same principle, but my object in

Fig. 5.

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admitting the water pressure to the inside of the instrument, was to utilize it in shifting the scale of the thermometer as the depths changed. The thing registered in such instruments is always the apparent volume of the liquid, and this varies with the temperature and the pressure. Hence the indications will represent the sum of the effects of the change of temperature and of pressure. If from any independent source we know either of these, we can determine the other. In a sea of uniform temperature throughout its depth, the apparent volume of the liquid would diminish as the pressure increased, and if the temperature increased with the depth, the apparent volume of the liquid would diminish at a slower rate; but it would be always possible to determine the true temperature as long as it did not increase at so great a rate as to dilate the liquid more than it was compressed by the increasing pressure. For the investigation of seas such as the Mediterranean, this form of instrument is most valuable. The method of determining accurately both depth and temperature from the combined reading of a mercury and a water piezometer is explained in the paper communicated to the Chemical Society.*

In the great majority of cases, the most convenient instrument to use is the form of Six's thermometer with protected bulb known as the Miller-Casella thermometer, with the following additions and improvements, which Mr. Casella has applied to them at my suggestion. The size of the instrument is increased so that the degrees are wider apart, a degree Fahrenheit on the minimum leg occupying about three millimeters of its length. Besides the scale of degrees which is attached in enameled slips to the vulcanite at the sides of the stem, there is an arbitrary (millimeter) scale etched on the stem itself. The valves of the division of this scale are ascertained by a careful comparison with a standard thermometer. It is thus possible to read with certainty to a quarter of a millimeter or a twelfth of a degree Fahrenheit. The errors due to the scale not being rigidly attached to the thermometer, and to the difficulty of determining the height of the index by reference to a scale, at the side of, instead of over it, are eliminated. Finally, by having the ordinary scale at the side, the instrument can be used independently of the arbitrary scale, and, even where the arbitrary scale is principally relied on, the scale of degrees enables the observer to know very approximately the true temperature at the moment of observation, without reference to tables, and, by noting on every occasion the reading on both sides, the chance of errors from misreading is greatly reduced. The maximum leg, which is only rarely used, is of larger bore than the minimum one; the degrees, therefore, are closer, and the temperature of the instrument may rise as high as 100° Fahr., without the index entering the terminal bulb. This is a detail of considerable practical importance, for it is impossible always to protect the thermometers, when on deck, from the direct rays of the sun, which would speedily disable the maximum side of the thermometer, if its range were as limited as that of the minimum one.

It will be seen, from what has been said, that there is no one instrument which fulfills all conditions required of a perfect deep-sea thermometer. It is necessary, therefore, for the investigator to use his judgment in the selection of the instrument best suited for the particular case before him. In order to be prepared for possibly occurring cases, he should be provided with thermometers of (*a*) the Miller-Casella type, with improvements just described; (*b*) the mercury piezometer, (*c*) the Negretta and Zambra inverting thermometer. It is well to have several of the first class (*a*), as any number of them can be attached to the line at different depths, and thus much time saved. In my own practice, I generally use four or five at a time. It is not advisable to exceed this number, as the loss in case of accident would be too heavy. Considering the distribution of temperature actually found in lakes and seas of warm and temperate regions, this is the most generally useful instrument, when thorough investigation by means of series of observations is intended. In the particular and frequently occurring case of an enclosed sea, containing a large mass of water, showing no variations of temper-

* *Journal of Chemical Society*, October, 1878. The blocks of Figs. 2, 5, 6 have been kindly lent by the Council of the Chemical Society.

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ature when tested by this instrument, it must be replaced by the mercury piezometer (*b*), which possesses the advantage that the position of thermometric scale shifts along the stem according as the depth varies. Also, any number of them can be used at the same time at different depths on the same line. The inverting thermometer of Messrs. Negretti and Zambra (*c*) is the instrument most suitable for isolated observations. It is also of very great use for supplementing and controlling the observations with the other instruments, especially in the case of sea lochs or fjords, where the temperature distribution is often much disturbed by the imperfect mixture of fresh with salt water.

For the successful and expeditious crrrying out of deep-sea temperature observations, the investigator should be furnished with an improved Miller-Casella thermometer for the bulk of the work, and the mercury piezometer and the investing thermometers for particular cases. All the thermometers, of whatever type, should be carefully compared with a good standard, and the result stated in terms of its scale.

For the determination of the specific gravity of the water, it is necessary to have an instrument of considerable delicacy, which can be used in all moderate weather at sea. The specific gravity of a liquid is ordinarily determined in one of two ways, either with the specific gravity bottle, when the weight of a known volume of the liquid is directly observed, or with the hydrometer, when the volume of a known weight is observed. A special modification of the hydrometer, namely specific gravity bulbs, has long been in use for special purposes, and they have been used by Dr. Carpenter and others for sea work. The only objection to their employment, in work of purely scientific interest, is that each bulb, being in effect a separate hydrometer, has to be separately tested for its weight and volume, and for change of apparent density with changes of temperature. With the large number of bulbs which is necessary, this involves an enormous amount of labor expended, without corresponding advantage. Sets of hydrometers, graduated so as to include all specific gravities naturally occurring in the sea, have been used. When each hydrometer has been constructed of the requisite delicacy, and of workable proportions, it is necessary to have a set of ten hydrometers; and the same objection obtains as in the case of the bulbs. For the work of the "Challenger," an instrument of suitable size and proportions was constructed. Its stem carried an arbitrary scale (millimeters), and was carefully calibrated: the weight of the whole instrument was also carefully determined, and also the dilatability of the body. The instrument was entirely of glass. By a contrivance similar to that used in Nicholson's hydrometer, weights could be placed on the upper sub-cavity of the stem. By this means the range of usefulness of one hydrometer can be extended far beyond the limits occurring naturally in the sea.

In prosecuting independently this work, I have improved on some of the details of the instrument, without, however, in any way altering its general character. In the "Challenger" instrument, the body was a cylinder, containing about four diameters in its length; in the heavier form it is a sphere of about the same volume, this materially reducing the length of the instrument. Instead of a small brass table, and weights to be laid on it, the weights are hollow brass cylinders, closed at one end, and widened to flange at the open end with others in the form of flat rings, which can be slipped over the cylindrical weights, and then rest on the flange. These are small mechanical details, which, however, greatly affect the handiness of the instrument, and they are therefore of importance. The following is a description of the instrument used for the whole of the work done during the cruise of the "Challenger." The stem, which carries a millimeter scale 10 centimeters long, has an outside diameter of about 3 millimeters, the external volume of the divided portion being 0.8607 cubic centimeter; the mean volume of the body is 160.15 cubic centimeters, and the weight of the glass instrument is 160.0405 grammes. With this volume and weight, it floats in distilled water of 16° C. at about the lowest division (100) of the scale. In order to make it servicable for heavier waters, a small brass table is made to rest on the

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top of the stem, of such a weight that it depresses the instrument in distilled water of 16° C. to about the topmost division (0) of the scale. By means of a series of six weights, multiplies by 1, 2, 3, 4, 5, and 6, of the weight of the table, specific gravities between 1.00000 and 1.03400 can be observed. It is not necessary that these weights should be accurate multiples of the weight of the table; it is sufficient if they approach it within a centigramme, and their actual weight be known with accuracy. The weights of the table and weights in actual use are:

Weight of table.....	0.8360	grammes.
Weight of weight No. I.	0.8560	"
" " II.	1.6010	"
" " III.	2.4225	"
" " IV.	3.1245	"
" " V.	4.0710	"
" " VI.	4.8245	"

For oceanic waters, the hydrometer is always used with the table, and either No. IV. or No. V. weight.

When the mechanical part of the construction of the instrument was finished, with the exception of the closing of the top of the stem (which, instead, was widened into a funnel shape, large enough to receive the ordinary decigramme weights), the calibration of the stem was effected by loading the stem with successive weights, and observing the consequent depressions in distilled water of known temperature. This done, the top was sealed up, and the instrument carefully weighed. The expansion of the body with temperature was determined in a similar manner, by reading the instrument in distilled water of various temperatures. The coefficient of expansion of the glass was then found to be 0.000029 per degree Centigrade.

For using this instrument at sea, about 900 cubic centimeters of sea water are taken, and the containing cylinder placed on a swinging table, in a position as near the center of the ship as possible. The observation with the hydrometer, loaded with the necessary table and weight, is then effected in the ordinary way, the accuracy of the readings being but little affected by rolling; pitching, however, is found to have a distinctly disturbing effect; and when it is in any way violent, it is advisable to store the specimen of water till the weather improves.

The temperature of the water at the time of observation is determined by one of Geissler's "Normal" or standard thermometers, graduated into tenths of a degree Centigrade; and it is essential for the accuracy of the results that the water, during the observations of the hydrometer, should be sensibly at the same temperature as the atmosphere, otherwise the changing temperature of the water makes the readings of both the hydrometer and the thermometer uncertain. At low temperature (below 10° or 12° C.) a tenth of a degree makes no sensible difference in the resulting specific gravity; but, at the high temperatures always found at the surface of tropical seas, rising sometimes to 30° C., the same difference of temperature may make a difference of three to four in the resulting specific gravity.

Having obtained the specific gravity of the water in question, at a temperature which depends upon that of the air at the time, it is necessary, in order that the results may be comparable to reduce them to their values at one common temperature. For this purpose a knowledge of the expansion of sea water with temperature is necessary.

This had been determined with sufficient accuracy for low temperatures by Despretz and others; but as the temperatures at which specific gravity observations are usually made are comparatively high, their results were of but little use, directed as they were chiefly to the determination of the freezing and maximum density points. When the late Captain Maury was developing his theory of oceanic circulation, owing to difference of density of the water in its different parts, he found the want of information on this important subject. At his request the late Professor Hubbard, of the National Observatory, United States, instituted a series of experiments, from which he was enabled to lay down a curve of the volumes of sea water at all temperatures, from considerably below the freezing point to much above what obtains even in the hottest seas. The results are published in Maury's "Sailing Directions," 1858, vol. i., p. 237, and have evidently been carried out with great care. The composition of different oceanic waters varies, even in extreme cases, within such close limits that the

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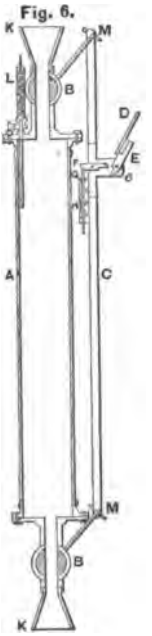
law of thermal expansions is sensibly the same for all of them; of this, Hubbard's experiments afford satisfactory proof. In the table which gives the results of all his experiments, he takes the volume of water at 60° Fahr. as his unit. In order to avoid much useless calculation, I have been in the habit of reducing my results to the same temperature (15.56° C.), while, for a like reason, I have retained the specific gravity of distilled water at 4° C. as the unit. The choice of a common temperature, to which the results should be reduced, and of a unit of specific gravities, is a purely conventional matter; and in choosing the above-mentioned ones, in the first instance, I was moved solely by a desire to save calculation. For every water, however, there is one temperature to which it would be natural to reduce its specific gravity, namely, the temperature which the water had when in its place in the ocean; and in this sense all my results during the cruise have been reduced. Hubbard's table of the change of volume of a mass of sea water, with change of temperature, enables us very easily to reduce any observed specific gravity from the temperature of observation to any other temperature, say 15.56° C.

Collection of Samples of Water.— The water from the bottom was usually collected in the so-called "slip" water bottle, which has been described by Professor Jacobsen. Water from intermediate depths is obtained in an instrument represented in section in Fig. 6. It is made entirely of brass, which, however, might advantageously be nickel-plated. It consists of a cylinder A, terminated at both ends by similar stop cocks B B, which are connected by the rod C. This rod carries, near its upper extremity, a piece of stout sheet brass D, 10 centimeters long by 15 broad, soldered to the casting E, which is movable about the axis *e*. The function of this part of the apparatus will be more easily explained by describing the manipulations necessary when collecting water.

When intermediate water is to be obtained, the water bottle is firmly attached to the sounding line, which carries at its end usually a lead of 56 lbs. or 1 cwt.; the stop cocks are then opened, giving them, with the rod C, the position represented in the figure. The line is then lowered carefully by hand, until the water bottle is close to the surface, when it is let go, and the line allowed to run out without a check. During its passage downwards the water courses freely through it, being considerably assisted by the conical end pieces K, K. When the requisite depth has been reached, the line is

Fig. 6.



checked again at the same mark, and finally hauled in altogether by the donkey engine. When the line is hauled in at first the flap D falls down into a horizontal position, when it is caught by the movable piece of brass F, which moves around an axis *f*, and is supported on the side opposite to E by the rod G, which rests on the spiral spring H. The water rushing past D, when thus in a horizontal position, exercises a sufficient pressure upon the rod to close the stop cocks B, B. When the speed with which the bottle is hauled through the water is increased, the pressure on D becomes so great, that it overcomes the tension of the spring H, and E passes the catch F, when the rest of the journey upwards is performed with the flap, D, hanging down, and therefore offering the least possible resistance to the water. The object of at first hauling in only a couple

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of fathoms or so, and letting the line go again, is to insure the cocks being closed. For, supposing after the first hauling in they were not quite closed, by letting the instrument descend through the water the flap D sets itself again, and, on heaving in, it shuts down the stop cocks, which were before but partially closed; or, if they were closed before, it only shuts them the tighter. When the water bottle has been brought it is only necessary to substitute for the lowermost brass funnel a small nozzle, when the water may be tapped into any vessel destined to receive it. This done, the bottle may be at once lowered to any other required depth, much time being spared by not having to detach it each time. At the upper end of the bottle a small spring safety valve, I, is introduced, in order that the considerably denser water from below may be able to make room for itself as the surface is approached. In order that the instrument may properly do its work, it is evident that, first, the stop cocks should be so stiff that the weight attached to their levers be not sufficient to close them; and, secondly, the spring H should be so strong as to ensure the shutting of the cocks before it itself gives way. These conditions are secured by the following means of adjustment. The stop cocks can be made stiff in the usual way, by lightening the screws which screw the "keys" in the bands; the tension of the spring H can be increased or diminished by means of a screw at the lower end of the tube containing it; and the mobility of the stop cock can be regulated by means of the screws M, M. Although from this description the operations of adjustment may appear complicated, it is, in fact, practically very simple. After the first time of use it is rare that any further adjustment is required than a turn of the screws M, M. The diameter of the apertures at either end is necessarily smaller than that of the cylinder; it is, therefore, impossible for the water in it to be entirely changed while descending through a distance equal to its own length. It became a question, therefore, for experiment to decide what actually was the rate of change of water. To this end a few experiments were made in a fresh water lake. The bottle being filled with water containing some yellow prussiate of potash was sunk in the lake, until the surface of the water was on a level with the upper stop cock when the stop cocks were opened, and the lime let go. On being brought up again the contents were treated with the solution of perchloride of iron. It was found that, when the bottle had been sunk to a depth of a fathom and a-half, the water had been entirely changed, the iron solution being wholly without action on it. We may be certain then that the water which we obtain by this means is an average of the last two fathoms through which the bottle has passed.

The weight used as a sinker should be chosen so as to impart sufficient velocity not to lose time unnecessarily over the operation, and, at the same time, not to give an excessive velocity at the depth where the water is to be collected, because the rate of change of water depends on the friction of the water inside the bottle, and so on the velocity of descent. In practice, for depths over 100 fathoms, a weight of 112 lbs. was used, and for depths from 25 up to 100 fathoms, a weight of 56 lbs. was used. For less depths the weight of the bottle itself was sufficient. The velocity of descent at the depth where the water is to be collected should not exceed 12 feet per second. The mean velocity for the interval between 75 and 100 fathoms from the surface was, with 66 lbs., nine feet, and with 112 lbs. eleven and a-half feet per second.

When once let go, it is essential that the line should run out to the required depth without a check; it is then, however, immaterial, as far as the water bottle is concerned, what interruptions occur in heaving in. The fulfillment of the condition of running out without a check never presented any difficulty on board the "Challenger," depending as it does on the care of those who take the line. When, however, by accident a check does occur, the line is stopped, and the water bottle brought up again, reset, and sent down again. In order to utilize any such accidents, it is usual to take the water from the greatest depth first; then, if a check does occur, it may occur at one of the desired intermediate depths, and so no time would be lost. In designing the water bottle, it had been my intention to use it not only for collect-

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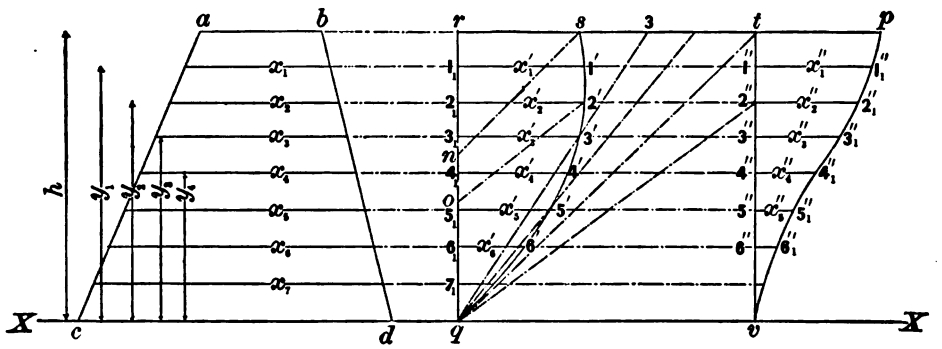
ing water, but also as a flask, so that the atmospheric gases could be boiled out of it without transvasing the water. In practice, however, I have not been able to get air-tight stop cocks, besides which, it would make an inconveniently large apparatus in a very small laboratory. I have spoken of this water bottle as being only used for intermediate waters, but there is no reason why it should not be used for bottom water; indeed, where the sounding lead does not weigh over 1 cwt., it is frequently used for this purpose. In the case of deep soundings however, where a weight of three, and sometimes four hundred weight is used, the "slip" water bottle is always preferred.

MOMENT OF INERTIA OF PLANE FIGURES OF ANY FORM.

By LIEUT. G. S. CLARKE, R.E.

From Papers of the Royal Engineer Institute.



THE moments of inertia of figures of simple geometrical form are most readily found by integration. Those of irregular figures, such as a rail section, can be determined by graphic methods alone.

The following simple general method is believed to be entirely new.

Suppose that the moment of inertia of the trapezium *abcd* about any axis XX is required. Draw any ordinates $x_1, x_2, \ldots$ of the trapezium and produce them as shown. Draw any line *rq* perpendicular to XX. Let $y_1, y_2 \ldots$ be the respective perpendicular distances of $x_1, x_2 \ldots$ from XX, and let *h* be the perpendicular height of the trapezium. From *r* set off *r*3 equal to any ordinate x_3; join 3*q* cutting x_3 produced in 3′. Repeat the process for all the other ordinates $x_1, x_2, x_4, \ldots$ (obtaining the points 1′, 2′, 4′...) finally make $rs=ab$.

Let $x_1', x_2', \ldots$ be the ordinates of 1′, 2′, ... measured from *rq*; *i.e.*, $x_1'=1_1 1'$; $x_2'=2_1 2'$, etc.

Then:

$$\left.\begin{aligned} \frac{x_1'}{y_1}&=\frac{x_1}{h};\ \text{or, } x_1=h\frac{x_1'}{y_1}\\ \frac{x_2'}{y_2}&=\frac{x_2}{h};\ \text{or, } x_2=h\frac{x_2'}{y_2}\end{aligned}\right\} \quad \ldots\ldots \quad (a).$$

and so on.

Now the moment of inertia (I) of the trapezium about XX is $\Sigma(x_1'y_1^2)=h\Sigma(x_1'y_1)$ but $\Sigma(x_1y_1)=Y.\Sigma(x_1')$

Where Y is the distance of the center of gravity of the figure *rsq* from XX. Hence calling A the area of the figure *rsq*

$$I=h.Y.A.$$

To determine I, therefore, it is necessary to know the area of *rsq*, and also the position of its center of gravity.

So far the construction is of course perfectly well known.

Now, make $rt=h$ and draw *tv* perpendicular to XX, and cutting the produced ordinates in 1″, 2″ ...; join any of these points; *e.g.*, 2″ to *q* and draw 2′0 par-

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allel to $2''q$. Call the distance $2_1 0$, x_2'' and set off x_2'' horizontally from $2''$, thus obtaining the point $2_1''$. Repeat the construction in the case of x_1', x_2', . . . thus obtaining the ordinates x_1'', x_2'', . . . and the points $1_1''$, $3_1''$, . . . ; finally draw sn parallel to tq and make $tp = rn$.

Then:

$$\frac{x_1''}{1_1 q} = \frac{x_1'}{1_1 1''}, \text{ or, } x_1'' = \frac{x_1' \cdot y_1}{h}$$

Similary $x_2'' = \frac{x_2' y_2}{h}$ and so on, but from (a)

$$x_1' = \frac{x_1 y_1}{h}; \quad x_2' = \frac{x_2 y_2}{h}; \text{ etc.}$$

Hence $$x_1'' = \frac{1}{h^2} x_1 y_1^2$$

$$\Sigma(x_1'') = \frac{1}{h^2} \Sigma(x_1 y_1^2)$$

But $\Sigma(x_1'')$ = the area of the figure $tpv = A'$ and $\Sigma(x_1 y_1^2) = I$. Hence

$$I = A' . h^2.$$

Since h is known it is merely necessary to obtain the area of the figure tpv. This can be done by cutting it up into approximate trapeziums, or very conviently by a planimeter.

The curve sg, which need not, of course, be drawn, is evidently a parabola.

The method is perfectly general and can be applied with equal facility to figures of all forms with any positions of the axis XX, and its great simplicity will be appreciated by any one who tries it.

The construction requires very little more time than the ordinary one, and when completed, it remains merely to find the area of a figure instead of an area and a center of gravity.

THE GASKILL COMPOUND PUMPING ENGINE.

By JOHN W. HILL, M. E.

The Gaskill pumping engine is a new design of compound engine for city water supply, built by the Holly Manufacturing Company, of Lockport, N. Y., the first specimen of which was furnished the City of Evansville, Indiana.

By the courtesy of the trustees I am permitted to publish the following preliminary report upon the performance of the engines:

Committee on Water Works:

Gentlemen—Acting under your instructions, in behalf of the City of Evansville, I have made test trials of the engines recently erected in your pumping house by the Holly Manufacturing Company, of Lockport, N. Y., for your city water supply, and have to report to you thereon as follows:

The engines, two in number, are of the compound condensing type, with cylinders set parallel, and centers separated eight feet. The high pressure cylinder has a diameter of twenty-four (24) inches, and the low pressure cylinder a diameter of forty-one (41) inches. Each piston has a stroke approximately thirty-six (36) inches. The pistons of each engine are connected to cranks set at quarters on the fly wheel shaft mounted in bearings on the gallows frame overhead.

The contract between the City of Evansville and the Holly Manufacturing Company provides for "two sets of duplex pumping engines, each of four millions (4,000,000) gallons capacity each twenty-four (24) hours at a piston speed of one hundred and eight (108) feet per minute."

With engines pumping direct into the distributing mains, it is impossible to measure the water delivered through the force pipe by any of the usual methods, and as the supply is drawn from the river (Ohio) through long lines of suction pipe connected to the suction of the pumps, and subject to wide differences of head, it becomes practically impossible to measure the water on the suction side of the pumps. I have therefore adopted the only convenient method for determining the capacity of the engines, that of calculating the discharge and deducting therefrom a minimum slip.

The data for this purpose were taken by myself in the presence of your superintendent (Roberts) and a representative of the Holly Manufacturing Company, and are as follows:

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Engine No. 1:

H.P.	cylinder	pump	piston,	diam.,	17.98 ins.
"	"	"	" rod,	"	3.376 "
L.P.	"	"	"	"	18.00 "
"	"	"	" rod,	"	3.422 "
H.P.	"	"	" stroke,	"	35.965 "
L.P.	"	"	"	"	35.985 "

From which I estimate the capacity of engine No. 1 as

$$\frac{2(17.98^2\times.7854)-(3.376^2\times.7854)\times35.965}{231}=77.653$$

gallons, calculated capacity of the pump worked by the piston of H. P. cylinder per revolution, and

$$\frac{2(18^2\times.7854)-(3.422^2\times.7854)\times35.985}{231}=77.850$$

gallons, calculated capacity of the pump worked by the piston of the L. P. cylinder, per revolution, and aggregate calculated capacity of both pumps, per revolution,

155.503 gallons.

The mean stroke in feet of both pumps is

$$\frac{35.965+35.985}{2\times12}=2.9978$$

corresponding to

$$\frac{108\times60\times24}{2.9978}=25938.01$$

revolutions per day of twenty-four hours at "contract" piston speed of one hundred and eight (108) feet per minute, and capacity with an estimated slip of four (4) per cent. of calculated discharge, $155.503\times25938.01\times.96=3,872,101$ gallons.

Engine No. 2:

H.P.	cylinder	pump	piston,	diam.,	17.99 ins.
"	"	"	" rod,	"	3.376 "
L.P.	"	"	"	"	18.00 "
"	"	"	" rod,	"	3.422 "
H.P.	"	"	" stroke"		36.023 "
L.P.	"	"	"	"	35.967 "

From which I estimate the capacity of engine No. 2 as

$$\frac{2(17.99^2\times.7854)-(3.376^2\times.7854)\times36.023}{231}=77.882$$

gallons, calculated capacity of the pump worked by the piston of the H. P. cylinder, per revolution, and

$$\frac{2(18^2\times.7854)-(3.422^2\times.7854)\times35.967}{231}=77.811$$

gallons, calculated capacity of the pump worked by the piston of the L. P. cylinder, per revolution, and aggregate calculated capacity of both pumps, per revolution,

155.693 gallons.

The mean stroke in feet of both pumps is

$$\frac{36.023+35.967}{2\times12}=2.9995$$

corresponding to

$$\frac{108\times60\times24}{2.9995}=25932.6$$

revolutions per day of twenty-four hours at "contract" piston speed of one hundred and eight (108) feet per minute, and capacity with an estimated slip of four (4) per cent. of calculated discharge,

$155.693\times25932.6\times.96=3,874,628$ gallons.

The contract provides that the duty shall be eighty millions (80,000,000) foot pounds, per one hundred (100) pounds of coal burned under the boilers, with an evaporation from the temperature of feed of nine pounds of steam per pound of coal; and that the duty shall be estimated from the calculated discharge of pumps per revolution, the revolutions of engine during the trial, and the total head pumped against as the numerator of a fraction; the denominator of which shall be the net water delivered as steam to the engine divided by nine hundred (900). "The weight of water pumped to be taken at 8.34 pounds per gallon."

"Each engine to be operated continuously for twenty-four (24) hours for duty trial."

The duty trial of engine No. 1 commenced at 11.15 A. M., January 27th, and terminated at 11.15 A. M., January 28th.

The counter reading at beginning of trial, was.....	1392
And, at end of trial, was.....	27762
Difference—revolutions.....	26370

The head pumped against in feet, was:

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By gauge on force pipe.....	135.6931
By difference between center of gauge on force pipe and mean level of water in river during trial.....	29.055
By friction head suction pipe...	2.3806
By friction head force pipe.....	.161
By friction head 20″ elbow in force pipe.....	.0155
By allowance for resistance of water passages in pumps....	2.3
Total head.....	169.6052

The calculated discharge of pumps per revolution of engine has been stated as 155,503 gallons.

The water weighed to the boilers during the whole trial was 65228 pounds, from which is deducted the following quantities:

Drawn off to calorimeter.....	172.125
Leakage between weighing tank and boilers.....	50.322
Entrained in the steam, 1.98 per cent.....	1254.607
Total deduction.....	1477.054

and net steam delivered to the engine becomes 63750.946 pounds, corresponding to an expenditure of 7083.44 pounds of coal, upon the evaporation stipulated in the contract.

From which I estimate the duty of engine No. 1 as

$$\frac{155.503 \times 26370 \times 8.34 \times 169.6052}{70.8344} = 81,885,917.12.$$

The duty trial of engine No. 2 commenced at 10.45 A. M., January 29th, and terminated at 10.45 A. M., January 30th.

The counter reading at beginning of trial was.....	501
And at end of trial.....	27986
Difference—revolutions.....	27485

The head pumped against in feet was

By gauge on force pipe.....	141.372
By difference between center of gauge on force pipe and mean level of water in river during trial.....	32.437
By friction head suction pipe....	2.5925
By friction head force pipe.....	.1737
By friction head 20″ elbow in force pipe.....	.0169
By allowance for resistance of water passages in pumps	2.3
Total head.....	178.8921

The calculated discharge of pumps per revolution of engine has been stated as 155,693 gallons.

The water weighed to the boilers during the whole trial was 68238 pounds, from which is deducted the following quantities:

Drawn off to calorimeter.....	168.875
Leakage between weighing tank and boilers.....	50.322
Entrained in the steam, 4.7489 per cent.....	3230.145
Total deduction.....	3449.342

and net steam delivered to the engine becomes 64788.658 pounds corresponding to an expenditure of coal under the terms of the contract, of 7198.74 pounds.

From which I estimate the duty of engine No. 2 as

$$\frac{155.693 \times 27485 \times 8.34 \times 178.8921}{71.9874} = 88,688,866.4.$$

In regard to the capacity guaranteed for the engines, I am inclined to believe, in view of the stipulated dimensions of pumps and piston speed, that the incorporation in the contract of four millions (4,000,000) gallons capacity was unintentional, as the prescribed data of the contract prohibits this discharge.

You will observe that both engines have exceeded the contract duty, one by *nearly two millions*, and the other by more than *eight and one-half millions*.

In the general report, which I shall submit at an early date, will be given all the data taken during the trials, together with an inquiry into the precise performance of the engine, as developed from the indicator diagrams.

A PULVERULENT lubricating material for axles, shafts, &c., is prepared by Herr Drechsler, of Dresden, thus: The finest graphite powder is worked up thoroughly with egg-white, or yellow, or both, to a firm dough, which, in a metallic vessel, is kept in a vessel of boiling water, till the egg-white and yellow are fully coagulated. The mass is then dried at 90° C., so thoroughly, that it can be bruised or stamped to powder. This powder is applied to a slowly-revolving axle or shaft, till axle and bush take the peculiar dark shine of graphite.

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STREET CLEANSING IN PARIS.

By M. VAISSIERE.

From Foreign Abstracts of Institution of Civil Engineers.

The cleansing of the public thoroughfares in Paris, formerly undertaken by the Prefect of Police, is now a function of the Prefect of the Seine. The staff consists of two chief engineers, one for each group of arrondissements, one group being subdivided into three sections, each under the charge of an executive engineer; and the other into five sections, similarly supervised. These sectional engineers have under them fifty-one superintendents and sixty-one overseers, whose employment imposes upon the municipal budget an annual cost of 260,000 francs. The scavenging plant is kept in a central depot, where materials of every description are stored and classified, for ordinary and extraordinary service, when snow and ice render additional assistants necessary.

The depots contain supplies of chloride of lime, sulphate of zinc, sulphate of iron, and carbolic acid, as disinfectants; and hydrochloric acid, nitro-benzide (acide de mirbane), as cleansing agents. The chloride of lime, of a strength of 100° to 105°, is successfully employed for the disinfecting of places tainted with urine or fæcal matter, also for the cleansing of gutters carrying sewage water. Sulphate of iron and sulphate of zinc are both used under the same conditions. Sulphate of iron possesses the disadvantage of rusting objects to which it is applied. Sulphate of zinc is stronger in its action, but costs a little more. It produces no smell, nor does it leave any trace. It is much employed in summer for washing and watering the basements of the Halles Centrales, used for fish, poultry and offal. At a strength of $\frac{1}{8}$, and mixed with 3 per cent. of sulphate of copper, sulphate of zinc makes a good disinfecting liquor, which preserves its qualities a long time and is of great use in private houses. Carbolic acid is not, strictly speaking, a disinfectant; it does not act like chloride on putrid matter, but arrests and prevents fermentation, doubtless by destroying the spores. It is, therefore, always employed when it is desired to destroy the germs of putrid fermentation. It is used at a strength of about $\frac{1}{40}$, say a gallon of the acid to 40 gallons of water. At strengths of $\frac{1}{100}$ and $\frac{1}{200}$ it gives good results for watering once or twice a week in summer those parts of the Halles Centrales liable to infection. It is even used as low as $\frac{1}{1000}$ for watering streets and gutters. Hydrochloric acid is applied to urinals and slaughterhouses. In places much encrusted with tartar it is used at a strength of $\frac{1}{5}$. Lowered to $\frac{1}{10}$ it cleans smooth walls and flags efficiently. In ordinary rinsings a strength of $\frac{1}{15}$ suffices. It leaves a disagreeable odor behind, which is, however, quickly dissipated. Mirbanic acid (nitro-benzide) is more energetic than the foregoing, but it produces a disagreeable smell of bitter almonds, and leaves a white film which has to be washed off. It is used at the same strengths as hydrochloric acid. The annual cost for plant and disinfecting materials of all descriptions is £8,800 (220,000 francs).

The engineers of the city of Paris are also charged with the sweeping of the roads, an area of 12,916,800 square yards being cleaned between 3 and 6 A. M. in summer and between 4 and 7 in winter. The carts for removing the public and private refuse work from 6 to 8 A. M. in summer and from 7 to 9 in the winter. The filling of each cart is attended to by the driver aided by two shovelers, the latter having to provide during the rest of the day supplemental sweepings wherever required, to rinse the gutters twice a day, and to clear and disinfect urinals, &c. These matters are ordinarily finished by 4 o'clock in the afternoon, except in unfavorable weather. The engineers have all at their disposal a staff of:

	fr. c.	fr. c.	
2,200 men at from	2 50	to 4 0	per day.
950 women "	0 20	to 0 25	per hour.
30 children (boys) at		0 20	per hour.

In addition there are one hundred and

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ninety mechanical sweepers, and as each machine represents the effective work of ten men, the total scavenging staff may be considered as composed of nearly five thousand laborers.

The mechanical sweepers which, after numerous trials and much hesitation, have been introduced into Paris, are the English machine, improved by M. Sohy, and the machine of M. Blot, the former being preferred. The mechanism of both is simple, works with regularity, and occupies little space; it consists of a framework upon two wheels, with a seat for the driver. At the back is placed the sweeping apparatus, composed of an inclined circular bass broom, actuated by gearing driven from one of the wheels of the carriage. By means of a clutch the driver can from his seat easily put the broom in or out of gear. The machine is employed in all weathers, and works as well on paved roads as upon macadam or asphalt. Each machine weighs rather over 14 cwt., and can be drawn by one horse. It sweeps about 6,578 square yards per hour. The cost of the machine is £40, and its annual maintenance, exclusive of renewals of the brush, £8. The cost of a new brush is about £2 16*s.* (70 francs), which will work for from one hundred and sixty to one hundred and eighty hours.

The Paris mud no longer possesses the manurial strength of former times, and in consequence the receipts derived by the municipality from this source have greatly diminished. It is at present disposed of by public tender to responsible contractors for terms of about four years. For its removal there are daily employed five hundred and twenty carts, and nine hundred and eighty horses. The average bulk removed per day is about 2,223 cubic yards (1,700 cubic meters).

When a fall of snow occurs, attention is first directed to clearing the footpaths and crossings, so as to insure uninterrupted circulation of foot passengers. The town scavengers sand the roads wherever it is necessary for the carriage traffic. At the same time numerous auxiliaries are organized to remove the snow from the principal thoroughfares, in the order of their relative importance. For removing the snow the General Omnibus Company are bound by their concession to furnish fifty wagons, and carts are specially arranged for with the providers of sand and gravel at the beginning of winter, the contractors for maintaining the public roads being also bound to hold their carts at the disposition of the sectional engineers. In certain cases the half-melted snow is swept into the sewers, especially those carrying warm water. Melting by steam has been tried, when a continuous jet was introduced into a mass of banked snow, but it melted very slowly at first, and the melting ceased after the cavity had increased to a certain size. Two descriptions of snow plough are kept in store, one for manual, the other for horse power; but they have never been used, as the coating of snow seldom attains sufficient thickness, and as it is too quickly compressed and hardened by the traffic. As a rule the sum allowed in the budget, about £7,000, suffices for the extra labor incurred; but occasionally severe winters cause this to be greatly exceeded, as in 1875–76, when the increase amounted to £8,000.

Both hose and carts are used for watering the thoroughfares, the former for the boulevards, the avenues, and a certain number of first-class streets. The watering plant belongs to the municipality. Three descriptions of carts are in use, two heavy wooden ones are now being superseded by the third, Sohy's cart, made of sheet iron. The carts contain 220, 242 and 286 gallons respectively, and will water from 2,400 to 3,350 square yards. The watering by hose is attended to by the ordinary street cleaners, who can easily water 24,000 square yards in thirty-five minutes, deducting the time necessary to connect the apparatus with the mains. There are three hundred and twenty-two water carts, which on the average disperse 1,311,200 gallons of water over a surface of 7,139,-163 square yards. A surface of 2,783-,092 square yards is watered by hose, and this system is being greatly developed on account of its convenience and cheapness. The annual cost of watering is £18,000.—*Annales des Ponts et Chaussées.*

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REPORTS OF ENGINEERING SOCIETIES.

THE AMERICAN SOCIETY OF CIVIL ENGINEERS.—The January and February issues of Transactions, contain:

Paper No. 214. "The Strongest of the Bronzes; a Newly Discovered Alloy of Maximum Strength," by R. H. Thurston.

No. 215. "Renewal of Foundation and Transfer of a Lighthouse in Pascagoula Harbor," by J. W. Putnam.

No. 216. "The Sewerage of Memphis," by F. S. Odell.

The papers are fully illustrated and the discussions of the latter paper are of unusual interest.

POLYTECHNIC ASSOCIATION OF THE AMERICAN INSTITUTE.—At the meeting of the 17th March, the paper for the evening was by Prof. Plympton upon the aneroid barometer. This instrument has been greatly misunderstood, and has been much abused because people, in buying it, have often supposed that they would be able, by inspection, to read off the elevations at which they made their observations, in the same way that they would note the temperature upon a thermometer. Like the mercurial instrument, it is a measure of the pressure of the atmosphere at any given time.

In torrid zones, where the variations of pressure are sudden, especially those just preceding severe storms of wind, &c., the mercurial instrument does not indicate with sufficient rapidity. It is an accurate balance, though rather slow to swing. Its numerous disadvantages as a portable instrument were mentioned, and its construction illustrated experimentally. The construction of the aneroid was then described, and drawings were made upon the board. Almost a dozen different styles and sizes of instruments were then exhibited, from the 5-inch instrument to the delicate affair no larger than a watch.

The paper of March 24th was upon glass and cements, by Dr. John Phin, of the *American Journal of Microscopy*.

Cements are to be divided into four classes, according as they dry, congeal by oxydation, harden by cooling, or "set" by other chemical changes. First are those which harden by evaporation. Under this head may be classed paste, mucilage and their varieties. Glues to a certain extent dry.

The second class includes the oils. These are said to dry, but it is not by evaporation. They lose nothing, but absorb oxygen from the air. The cement weighs more after hardening than when first applied. Cements which congeal by oxydization cannot be treated in the same way as those of the first class. They require a larger time to handle. The hardening goes on from the outside inward. For example, mend a piece of porcelain with one of these cements. Test it in a few days, and although the outside will be hard the inside will not appear to have dried in the least, and will have no tenacity. Leave it for six months, and it will be very strong.

Thirdly, we have those cements which harden by cooling. These, instead of gaining their strength slowly, like those of class two, become hard at once. Shellac is a good example of a cement of this kind. China put together with melted shellac is extremely strong.

A fourth class of cements may be represented by plaster of Paris. This is the type of an extensive class, including the whole line of mortars and hydraulic cements on which depend our great engineering works, and even the houses in which we live. It forms a chemical compound combination with water first, and then more slowly hardens by drying a part of the water evaporating.

In order to use a cement successfully we must know to what class it belongs and treat it accordingly. Next, we must know how to put it on. In no case should it be used in a large quantity. The less the better is a good rule to follow.

In mortar we mingle sand, which makes the actual thickness of the lime between the stony surfaces in all cases very slight, however much mortar we may employ. In the use of glue this is not practiced or necessary. The joints made by carpenters are good examples of the minute quantity of a cement which is necessary. Place a well-made glued joint on the edge, and it is almost impossible to find the lines of glue. Its position is mainly discovered by the direction of the grain of the wood.

Intimate contact between the cement and the edges is necessary. This is not easy, on account of the layer of air which adheres to all bodies. This layer of air is what causes needles to float when carefully placed upon the surface of water. When an object is warmed the film of air is easily moved, the hot needle sinks, and to the hot body the cement will adhere easily. It is faulty for this reason, that in gluing it is needful to have the work warmed. The rubbing of the surfaces together gets rid of the air, and then not only with glue, but with all cements, the surfaces must be pressed closely together.

Common glue has most enormous strength and adhesive powers if it is good. But to be good it must not have been injured in the making by decomposition, to which the material and the glue itself are peculiarly subject. Here the lecturer detailed at some length the process of glue making, and said that if glue was not pleasant to both taste and smell it would not be strong. If not offensive, it could be trusted to hold wood more strongly than its own fibers.

The strongest known glue is that made from the skins and sounds of fishes, and the strongest of this class is made in Lapland from the skin of a perch. The Laplanders use it in making their bows, which are both strong and durable. In making it their cold climate is greatly in their favor; here a fish skin will begin to undergo decomposition before it can be dried.

In making it the skins are put into a bladder, which answers for a water bath, and heated in water until a sort of glue results. This

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glue is, as may be imagined, very elastic. Isinglass is a very strong glue, made from skins, sounds, &c., of fishes; it is very liable to be spoiled in making by overheating.

The pastes are all made from starch in some of its forms. Gluten is also used for a paste, but starch is the best. All additions of resin, &c., commonly recommended, are a damage to paste.

Dextrine, or "British gum," is of immense value in the arts as a cement. It is derived from starch by roasting or by the action of nitric acid. It was discovered by accidental overheating of starch, and its process of manufacture was for a long time kept secret. Its chief use for a long time was in the cotton manufacture. It is the standard gum for postage stamps, though it is said that gum-arabic and cheaper substitutes are used in this country.

No cement can be fire-proof which contains organic matter, since this is decomposed at a temperature about that of melting lead, or, say, 600° F. Cements containing oils will not be fire-proof.

Silicate of soda, mixed with asbestos, is the nearest to a fire-proof cement. It will stand a low, red heat. It is decomposed at a bright red.

Water proof glues are made in two ways. Glue and linseed oil are recommended, but I have had better success with the mixture. The chromates may be used with glue. These, when exposed to the light, render the compound insoluble.

Aquarium cement is the best water-proof cement I know. The formula is:

Litharge.....	3	Rosin	1
White sand.....	3	Boiled linseed oil..	–
Plaster of Paris....	3		

The solids are to be taken by measure in powder and mixed. As it sets rapidly, the set must not be added until it is wanted for use. It is better for being put into a mortar and pounded. It hardens in three days. It will hold glass firmly, and with it glass tanks may be made without frames, if the angles are well filled with cement. It is a kind of mastic, and could be used on brick.

What is technically known as marine glue stands almost by itself. Where it can be put on hot is admirable. It is composed of India rubber and shellac, dissolved in naphtha. Some kinds are hard, some almost liquid. I have seen this glue adhere to glass so firmly as to tear the glass when plates were separated.

In the discussion which followed, Dr. Parmalee gave some interesting experiences in the manufacture of marine glue. He said its melting point was about 230°, and in making it was injured if the heat was carried above this point. In applying it care should be taken not to go above this heat, as the melting point would be raised and the strength diminished. In applying it the soldering iron may be used, but its heat must be regulated.

In answer to Dr. Parmalee, Dr. Phin said that Jeffries, the inventor, put three kinds of marine glue in the market; that the kind he himself had used was that known as "D. H. K.," and he had had no difficulty in making it adhere to glass—a point which caused some surprise.

ENGINEER'S CLUB OF PHILADELPHIA, APRIL 2, 1881.—Dr. H. M. Chance described an attempt to extinguish the Kehley Run Colliery fire at Shenandoah City, by carbonic acid gas and nitrogen. The gas was generated in an open brick furnace with reversed draught, and forced into the mine through four 3-inch pipes, by injectors supplied with steam at 60 lbs. pressure. Each pipe was supposed to supply 1,500 cubic feet per minute, or a total of 6,000 cubic feet per minute. The attempt was entirely unsuccessful, and Dr. Chance attributes its failure principally to *the impossibility of making the mine airtight*, but also considers that the gas was delivered at too high a temperature, and that it was possibly mixed with carbonic oxide. The method seems to be worthy of further trial at mines that can be made thoroughly airtight.

Mr. P. H. Baermann described briefly the construction of the Cooperstown, N. Y., Water Works, and particularly the method of laying the supply pipe extending from the pump house up the Susquehanna River into Otsego Lake, a distance of 4,500 feet. The pipe was laid from a staging carried on 120 barrels, and lowered in 108 feet sections. Up to 9 feet in depth the joints were made with dry pine wedges, and above this with lead. The end of the pipe is provided with a copper strainer, which is in 38 feet of water and 10 feet above the bottom.

A paper was also read by Dr. Chance on "Wear in Wire Ropes," showing that the cause of rapid wear is often due to the use of drums, sheaves and pulleys of insufficient size, and that a great saving might be effected by increasing their diameters; especially that of the small deflection and knuckle pulleys and sheaves. The actual wear averages 0.138 cents in slopes, and 0.058 cents in shafts, per ton, for each hundred feet of lift.

ENGINEERING NOTES

ADVICES from Vienna state that the preparatory operations having been finished, the work of boring the great tunnel through the Arlberg has now actually commenced. This tunnel will be one of the longest in the world, though not so long as that of St. Gothard. So far the operations on the eastern side of the Arlberg have progressed very favorably. The rock there found is a micaceous slate, through which the contractors find it possible to advance at the rate of from three to four meters a day. On the western side, on the other hand, the advance of the tunnel is retarded, and the operations frequently disturbed by the repeated inrush of large quantities of water. The contractors were warned before commencing the work that this was only to be expected. The geologist further advised that the tunnel should be carried through a lower stratum of rocks, which are of denser material

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and watertight, but their warnings were disregarded.

THE PANAMA CANAL.—The *Panama Star and Herald* of February 3rd, says: "On Saturday afternoon, January 29, 1881, the French steamer Lafayette arrived at Colon with MM. Armand Reclus, G. Blanchet, and about forty other gentlemen, who are to be employed on the Panama Canal. For the present, and it is presumed permanently, the Canal headquarters will be in Panama, although Colon will be the main point for distribution of supplies, &c., for the work. The expedition is divided into two distinct sections or departments. M. Reclus is the general agent, with full powers from the Canal Company over all matters which may require his attention and decision on the isthmus. M. G. Blanchet is director of the canal works. It is understood that the work of the various sections and commissions is to be begun at once and pushed on with energy. It will relate principally to the exact location of the line for the proposed canal, clearing away the timber, brush, &c., thus opening up the country through which the excavation will be made; arranging matters of titles for right of way, buildings, &c., and the general land grants of the company, and other matters of a preliminary character which must necessarily precede the commencement of the actual work. A year or more must necessarily elapse before the employment of machinery will be necessary or possible, and in the meantime the number of laborers which will be needed will be comparatively small. The demand can be easily supplied at present, or for some time to come, on the isthmus or in the near neighborhood, and any great immigration of mere bone and muscle seeking employment in ordinary canal work is, for the present, unnecessary."

RAILWAY NOTES.

THE FIRST RACK RAILWAY IN PRUSSIA.—BY O. SARRAZIN.—The rich lead and silver mines of the Friedrichshagen Consolidated Company of Oberlahnstein are situated between Ems and Lahnstein, about 1½ mile from the banks of the Lahn. The company employs nearly one thousand work people, male and female, and in 1878 raised 14,000 tons of ore, which had to be transported at the rate of 46 tons a day down the valley to the river, there to be conveyed in barges to its destination. The system of land carriage being no longer equal to the requirements of the mine, it was determined to make a private railway on the Riggenback system. The line, which was opened on the 8th of November, 1880, is partly ordinary and partly rack railway. The difference of level between the two termini is 384 feet, which had to be surmounted in a length of 8,200 feet, thus giving 1 in 24.4 as the mean gradient. The steepest part worked by adhesion is 1 in 20.5, and by the rack rail 1 in 10. The racked portion is altogether 1,968 feet long, divided into three inclines of respectively 262, 1,165, and 541 feet each. The width of the gauge is 1 meter (3.28 feet). The curves on the racked portions are everywhere of a radius of 475 feet. At both ends, and at the middle of the line for the dressing floors, are sidings reached by switches of the ordinary construction, and a turntable affords access to the tracks laid in the works below. The teeth of the rack are 3.9 inches from center to center; it weighs 90 lbs. per yard, and cost about 22*s.* per yard at the works. The rails, 8¼ inches high, weigh 50 lbs. per yard, and cost £8 10*s.* per (metric) ton. In spite of the generally economical nature of the line, it was impossible to avoid some heavy works in cuttings and banks, the excavation in rock amounting to more than 15,000 cubic yards. It was also necessary to cross the line of the Nassau railway, the many streams in the valley, and the road leading to the Friedrichshagen works. Some of the bridges are of iron, but the greater part are of masonry. The working stock is at present limited to one locomotive and eighteen wagons. The engine, constructed in the works of the Swiss central railway at Olten, weighs 10 tons, or with fuel and water, 11.8 tons, and cost £1,120.

Its load is 10 tons up to the mine, and 18 tons down to the valley. The wagons weigh 0.9 ton each, and carry 2.5 tons. They are provided with brakes, and cost £32 10*s.* each. The greatest speed is six miles an hour. The line was begun in April, 1880, and was only seven months in making. It cost, including working stock, 150,000 marks (£7,500) or 60,000 marks per kilometer (£4,800 per mile), which compares favorably with similar lines in Switzerland, costing from 140,000 to 97,000 marks per kilometer. This makes the tenth railway in Europe on the Riggenbach system, the others being at Arth-Rigi, Vitznau-Rigi, Rohrschach-Heiden, and quarry lines at Ostermundingen and Laufen, and the Ruti line in Switzerland; Kahlenberg, and Schabenberg in Austria-Hungaria; and the Wasseralfingen line in Wurtemburg.—*Wochenblatt für Architekten und Ingenieure.*

ORDNANCE AND NAVAL.

THE NEW ARMORED CRUISER.—Active measures are being taken at Portsmouth for commencing the new armor-clad cruiser mentioned in the Navy Estimates for 1881-2. She will be constructed in No. 12 dock, within the extension works, a plan of building which has many advantages over the method usually adopted of building on a slip. All the weights, instead of having to be raised, will be dropped to where they are wanted, and when the ship is completed she will be simply floated out of dock, instead of having to be launched into the water by the expensive and complicated method adopted in the case of the *Inflexible*. The only drawback is the exposure to the weather, and this will be remedied by some temporary shelter. The length of the ship has been increased to 315 feet between perpendiculars, while her breadth is 61 feet, and her mean draught 24 feet 8 inches. About 120 tons of material, consisting of angle

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steel plates and rivets have already been demanded. A disposition of butts and edges of the bottom plating has also been submitted by the officials at Portsmouth, and approved by the Construction Department at the Admiralty, and every effort will be made to begin the ship as early as possible in the ensuing financial year.

NEW STEAM PINNACE.—A boat of a very novel design has been successfully tried in the Solent, and submitted to the dockyard officers at Portsmouth for their approval. It was built by Mr. S White, of East Cowes, and in size, shape, and general construction is almost an exact copy of the 48 feet steam pinnaces which he has supplied to the navy for guard and other purposes. The distinguishing feature of the new boat is the manner in which the deadwood and keel have been cut away to the extent of about one-half of its length, by which a free flow of water to the screw is secured. The advantage, however, does not consist in any accession of speed while going ahead, which remains the same, but in a considerable gain to speed in going astern, which it can do as rapidly as ahead, and in the remarkable handiness which the new principle confers in going round. A very small acquaintance with vessels is sufficient to show that when the helm is put hard over, the stem of a boat makes little forward progress, but is made the pivot upon which the stern revolves. As the stern is invariably the more deeply immersed, the result is that, in turning, the craft is compelled to force back a wall of water, which retards the boat in going round, throws great strain upon the rudder and gear, and increases the work of the engines. In cutting away the deadwood, the resistance of the water is reduced to a minimum as it escapes under the quarter, and the pinnace was found on trial to turn a complete circle under full power in one and a half of its whole length. The new design also enables the craft to stop almost dead, its way being arrested by a supplementary rudder, which is placed abaft the screw, and is worked simultaneously with the ordinary rudder outside. By placing this rudder at right angles with the keel, it acts as an effectual brake, and arrests the way of the craft. It was feared that the reduction of the depth aft would have the effect of diminishing the stiffness of the pinnace in turning, but practical tests have proved that the difference is scarcely appreciable. The great drawback which has hitherto attached to torpedo craft is the size of the circle which they require in turning, a defect which has been partially remedied by fitting a drop rudder forward. Should Mr. White's plan be found applicable to them, their activity in the water will be greatly increased by its adoption. The little craft was put through a severe trial. The behavior of the pinnace has answered every expection, while its remarkable handiness surprised the officers in charge. At a previous trial the boiler pressure, with closed stokehole, was 120 lbs. (the same as in the torpedo craft), while the air-pressure from the fans equaled 4 inches of water; the revolutions per minute were 435, and the horse power indicated 90. Six runs were made, the mean speed ahead being 12.356 knots per hour. Two runs were afterwards made with the screw going astern, the result giving an average speed of 10.14 knots, the revolution being the same. The steering qualities of the boat were next tested. when the absence of the after deadwood gave some remarkable results, the boat circling to starboard and to port in 30 seconds, or one-third the usual time, in a space having a diameter of 72 feet. With the engines going astern the pinnace turned in 1½ minute. As the propeller shaft revolves in solid water, and is only connected with the quarters by a bracket, there was a remarkable absence of vibration. The two rudders are simultaneously actuated by means of gearing and a double worm, which effectually locks the rudder. and thus enables the wheel to be left to itself.—*Times.*

BOOK NOTICES.

PUBLICATIONS RECEIVED.

ANNUAL REPORT OF THE STATE GEOLOGIST FOR THE YEAR 1880. 8vo. Paper. Trenton.

A LECTURE on the Progress of the Works of Completion of the New Improved Bed of the Danube at Vienna, and the lessons taught thereby; by Sir Gustav Wex. With five sheets of drawings. Translated by Maj. G. Weitzel, U. S. A. 8vo. Pamphlet. Government Printing Office. 1881.

THE WORKSHOP. No. 4, for 1881. New York: E. Steiger & Co.

REPORT OF THE U. S. WEATHER BUREAU for February.

NOTES ON RANKINE'S APPLIED MECHANICS. By Geo. I. Alden, B. S. Hartford. For sale by D. Van Nostrand. Price $1.75.

A small book for the use of students is here provided by the Professor of theoretical and applied mechanics in the Worcester Free Institute.

Students who have found difficulty in their study of Rankine will welcome this aid.

The so-called notes are given as supplementary to separate numbered articles of the applied mechanics.

The author has also added the graphic solution of a truss, and an investigation of the Peaucellier cell.

ELECTROTYPING—A PRACTICAL MANUAL. By J. W. Urquhart, C. E. London: Crosby Lockwood & Co. For sale by D. Van Nostrand. Price $2.00.

To say that this book is very well printed on tinted paper, and that the wood cuts, twenty-six in number, are mostly well executed, is to enumerate its chief merits.

It contains some valuable hints to practical workers, and devotes much space to the rudiments of electro-chemistry, but in either part it is too sketchy to prove of any special value to either the general reader or the artisan.

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MEASURES, WEIGHTS AND MONEYS OF ALL NATIONS. By W. S. B. Woolhouse, F. R. A. S. London: Crosby Lockwood & Co. For sale by D. Van Nostrand. Price 80 cents.

This is the sixth edition, enlarged, of a cheap form of a valuable book. It is of a convenient size (Weale series), and the tables are well selected and well arranged.

THE GAS ENGINEER'S DIARY AND TEXT BOOK FOR 1881. By G. E. Wright and Wm. S. Mason. Birmingham: Office of "Gas Engineer." For sale by D. Van Nostrand. Price $1.00.

The portion of this work which is termed the "Literary Section" will probably prove to be the valuable portion to gas engineers on this side of the Atlantic. This section is composed of several articles by different writers, specially prepared for this work and devoted to gas engineering and gas manufacture

A portion of the work is devoted to tables, formulas and statistics of special use to the working engineer.

RIVER BARS, THEIR FORMATION AND TREATMENT. By I. J. Mann. London: Crosby Lockwood & Co. For sale by D. Van Nostrand Price $3.00.

This thin octavo of seventy-five pages deals with admirable conciseness with an important subject.

The table of contents is as follows:

Chapter I. Bar Formation.
II. Wave Action.
III. Currents and Scour.
IV. Dublin Bar.
V. Dublin Harbor Improvement Schemes.
VI. Dublin Bar—Treatment by Induced Tidal Scour.

The illustrations, twenty-three in number, are good.

THE COAL FIELDS OF GREAT BRITAN. By Edward Hull, LL.D., F. R. S. London: Edward Stanford. For sale by D. Van Nostrand. Price $6.40.

This is of local rather than general interest. The descriptions of the geography and geology of the coal districts are exceedingly full and the maps are very fine.

A brief sketch of the coal fields of India and of North and South America closes the volume.

MINE DRAINAGE. By Stephen Michell. London: Crosby Lockwood Co. For sale by D. Van Nostrand. Price $6 00.

This a practical treatise on underground pumping machinery, with complete descriptions in detail of a large number of the best known engines

The contents are classified as:

Rotary Horizontal Engines, Non-Rotary Horizontal Engines, Rotary and Non-Rotary Vertical Engines.

As a book of reference for the mining engineer, the work must be of exceeding value.

A TECHNICAL TREATISE ON SOAP AND CANDLES, WITH A GLANCE AT THE INDUSTRY OF FATS AND OILS. By R. S. Cristiani. Philadelphia: Henry Carey Baird & Co. For sale by D. Van Nostrand. Price $6.00.

In this, as in all complete works on subjects relating to chemical technology, the chemical and physical properties of all the raw materials are fully discussed, and as in this case the number of substances is considerable, a large space is devoted to the natural history of an interesting class of bodies, which will render the book of value to many who are not interested in the processes of manufacture, to which the volume is otherwise devoted.

The illustrations are numerous and good, and serve to describe with great minuteness the latest improved methods.

IMAGINARY QUANTITIES, THEIR GEOMETRICAL INTERPRETATION. Translated from the French of M. Argand. By Prof. A. S. Hardy. For sale by D. Van Nostrand. Price 50 cents.

This essay forms No. 52 of the Science Series, and is presented just as it appeared in the pages of this magazine.

It is of the class of essays which most students, who take delight in mathematics, will read with pleasure and profit. It will interest more readers than do the heavier articles of the mathematical journals, inasmuch as the subject is one presented to the student almost at the beginning of his algebra.

The notes of the translator will, we think, be read with quite as much interest and profit as the original essay.

SYNOPSIS OF THE FRESH-WATER RHIZOPODS. Compiled by Romyn Hitchcock, F. R. M. S. New York: Romyn Hitchcock. For sale by D. Van Nostrand. Price 75 cents.

This is practically a descriptive catalogue of this interesting group of Protozoa. The characteristics of the genera are given with satisfactory fullness; then follows a list of species with the principal features described, after which each species is described with great minuteness.

The book will prove a great aid to students who collect microscopic organisms, and, indeed, is calculated to stimulate many to begin such work.

ELECTRIC LIGHTING BY INCANDESCENCE, AND ITS APPLICATION TO INTERIOR ILLUMINATION. With 96 illustrations. By William Edward Sawyer. 8vo. New York: D. Van Nostrand. 1881. Price 2.50.

This is a book of great practical value to all who wish to understand the subject. The style is exceptionally clear and comprehensive. We, of course, perfectly understand that the book is written in order to introduce the Sawyer system of lighting to the general public; therefore, the closing words of the preface, implicitly carried out as they are throughout the whole book, appear noble by comparison with many books of the same order. We quote: "Those who expect to find them devoted to criticism of the labors of other experimentalists will be equally disappointed. In

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the position of an impartial student and observer, I have sought less to indicate defects than to exhibit accomplishments."

Of the work, fifty-three pages are devoted to a full description of all the types of dynamo machines, of which only ten describe the Sawyer. Thirty-three engravings fully illustrate this portion of the book. A view of each machine, with diagrams of internal construction in detail are given, and explained in the text with unusual clearness and perspicuity. Especially is this the case in the winding of the wires in the various methods of construction, so that any intelligent mechanic could, from the drawings and text, easily construct any of these machines. The various physical laws are introduced incidentally, as occasion requires. The writer has not seen any book from which so much detail can be learned as from this.

As the Sawyer light is of the incandescent class, of course the book treats of that class in particular, devoting sixty-one pages of text and thirty-two engravings to the lamps and carbons, nearly one-half of which is taken up with other patents. The details of the Edison alone are illustrated by seven diagrams, giving the best idea of the process of manufacturing the Edison lamp we have seen; also, a fine view of the Maxim form. As a part of the lamp, twenty pages and five plates are devoted to the manufacture and preservation of carbons. A page diagram is given of the Sprengel pump, as used by Edison and others. All conflicting patents appear to be given, with dates. The chemical notes beginning page 105 are excellent. His remarks, page 103, upon the comparative cost of arc and incandescent lighting present the subject so clear that we quote: "Light by incandescence is considerably more costly than light by the voltaic arc, when the volume of light obtainable is the sole consideration. The same expenditure of power that will produce a light of 1000 candles by the voltaic arc will not produce, on an average, more than half or one-third as much light as incandescence in a divided circuit. It should not, however, be forgotten that the power of any light decreases as the square of the distance from it, and that one-fourth of the light of the arc, distributed at four or five appropriate points, thus reducing the power of each light to $\frac{1}{4}$ of that of the voltaic arc, will give substantially as good a general illumination as the arc. The incandescent light is whatever may be desired. The arc light is necessarily a powerful one. The objection to it, if used without a shade, is its great intensity and ghastly effects; and in order to obviate these defects, glass shades of more or less opacity are employed, which, according to tests, involve a wastage in light of,

With ground glass.....	30 per cent.
With thin opal glass.....	40 "
With thick opal glass.....	60 "

In some cases wastage is nearly 75 per cent."

Experiments in France on the Jablochkoff, with the necessary opalescent globes. "it is found that only 48 per cent. of its full power is available." "It is proper to remark that the light of the incandescent carbon is very unlike that of the voltaic arc. Its characteristics are the characteristics of daylight; and this is true to such an extent that, from its soft and agreeable nature and absence of glaring effects, the degree of illumination afforded is not always readily appreciated." Besides, incandescent lights *do not* require shades.

Chapter IX. treats of "the division of the current and light;" a most interesting chapter, because of the widely different opinions of physicists upon the subject. This should be read by all who are interested, as the author states his case and calculations clearly. If verified by future experiment they are of great value, but only actual experiment can decide.

Chapter X is devoted to a description of the Sawyer regulator, called here the switch—a most important part of the system, as by it the light is almost instantly turned up or down, giving any degree of intensity of light as required by the person using it. The subject is illustrated in ten perspective and six diagram views, including the current regulator, one being a fine view of the Maxim governor. While these regulators admirably perform their functions, he is careful, in perfect candor, to inform the reader (page 149) that, "By means of these regulators the changes in the circuit occasioned by the Sawyer switches for graduating the light are instantly balanced. But the fact remains that as much power is expended in driving the generator when there are a few as when there are many lamps in a circuit, and in a general distributing system, where economy is the prime consideration, such regulators, however perfect in their operation, can have no practical application." We venture to remark that this is not a peculiar defect of the electric light, but is a foundation principle governing every other industry.

Chapter XI is devoted to the consideration of the Sawyer patent for lighting the buildings in the blocks of a city by electric lights. The history, plans, meters, switches, etc., requisite are fully set forth in the text and eleven diagrams. It also deserves careful study. In it the "Niagara Falls problem" is discussed at length, and, to our mind, settles that question.

The last chapter is devoted to the commercial aspects of the subject—that omnipotent question, "Will it pay?" This chapter involves so many points, exhibits so many tables and calculations, which must be most carefully studied before an opinion can be given, that we have not time this month to devote to it. It is in print, in the book, for all interested to criticise.—*Journal of Franklin Institute.*

SHOCK'S STEAM BOILERS.—In the issue of March 4, 1881, *The Engineer*, of London, devotes nearly a column and a half to a review of the recent work on "Steam Boilers," by Engineer-in-Chief W. H. Shock. U. S. N. The reviewer calls it "the most important treatise on boiler engineering with which we are acquainted," and gives great praise to the illustrations, paper, printing, binding, etc. He says: "The plates are working drawings, which only require to be enlarged to be fit to send into the shops, and in the matter of constructive de-

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tails they show much that will be found novel and useful by English engineers." It is not, however, clear to the mind of the American engineer why he should call the bracing of the rectangular boiler, shown on plate 18, "a curious example" of "misplaced ingenuity." On this plate the best American practice of bracing rectangular boilers is illustrated, and the devices are in no way novel; but it is true that English practice, even in so-called first-class work, is, in many respects, very inferior to this. While summing up his opinion of the book in the last paragraph, the critic calls it "the most complete treatise on the marine boiler ever written," in which there is little to call for adverse criticism; and says further on, "it brings our knowledge of it (boiler engineering) down to the latest date and the questions which may be asked, and the answers to which cannot be found between the covers, must be few and far between," he makes the unreasonable complaint that it does not give a satisfactory answer to *all* the perplexing questions which now disturb the mind of the marine engineer. The critic finds fault with the writer for following closely in the footsteps of Rankine, in the chapters on combustion, transmission of heat and evaporation; but he does not point out a single fact which requires correction, nor does he indicate a safer guide. It is hardly fair in the critic to give it as his opinion that the investigation of the laws governing the draught of chimneys is simply inserted "to give an air of erudition to the work." If he had studied this chapter carefully he would have found that a number of very important conclusions are drawn from this investigation. From the fact that the rules given in the book regarding the management of boilers do not differ essentially from English practice, the reviewer concludes that they are directly derived from it. This may be pardonable in an English critic. The reviewer desires fuller information regarding the use of steel for boilers. He should, however, be aware of the fact that many questions relating to this subject will necessarily remain unanswered for years to come. For the enlightenment of the critic, we add that steel boilers have been introduced into United States Naval vessels since the last three years and have given the most satisfactory results. This is due, no doubt, in a great measure, to the superior quality of the material employed, which is entirely free of the defects found in many English steels, that cause so much trouble to the English boilermaker. It will be seen that the few unfriendly criticisms, seasoning the high praise given to the book, are mostly trivial and unreasonable; the critic has been looking for new theories, but the author has given nothing but established facts, because the latter are more needed than the former.—*Army and Navy Register.*

MISCELLANEOUS.

GEOGRAPHICAL NOTES.—On Tuesday night, at the Royal Institution, Mr. Edward Whymper described his ascents of Chimborazo and Cotopaxi to a distinguished audience. While purely athletic mountaineers had his sympathy in the practice of mountaineering as a sport, Mr. Whymper confessed that his sympathies were much more with those who employed their brains as well as their muscles. His journey to the Andes was to be one of work, and all its arrangements were devised so as to economize time to the uttermost. In observations for altitudes and position, in studying the manners and customs of the country, in photography and sketching, in the collection of objects of interest, from beetles on the summits of mountains to antiquities buried in the ground, he found quite sufficient to occupy his time. From Bodegas the party was composed of two Swiss mountaineers, the cousins Carrel, of Val Tournache, Mr. Perring, some muleteers, and their teams. When they reached the summit of Chimborazo, on the 3rd of January, after a most arduous climb, they found the wind blowing at the rate of 50 miles an hour, from the northeast, and driving the snow before it. With extreme difficulty, a reading of the mercurial barometer was effected. The mercury fell to 14.1 inches with a temperature of 21° Fahr. This being worked out, in comparison with a nearly simultaneous observation at Guayaquil, gave 20,545 feet for the height of Chimborazo. They began the descent at 20 minutes past 5, with scarcely an hour and a quarter of daylight, and reached their camp (about 17,400 feet above the sea level) about 9 P. M., having been out nearly sixteen hours, and on foot the whole time. Passing from an extinct to an active volcano, Mr. Wymper next gave an account of his journey to the crater of Cotopaxi. Observing with the telescope, during an enforced stay at Machachi, that much less smoke or vapor was given off at night than by day, he resolved; if possible, to pass a night on the summit. On the 18th of February the party got to the edge of the crater, having passed almost the whole way from their camp at a height of 15,000 feet to the foot of the final cone over snow, and then over ash mixed with ice. The final cone was the steepest part of the ascent, and on their side presented an angle of 36 degrees. When they reached the crater vast quantities of smoke and vapor were boiling up, and they could only see portions of the opposite side at intervals, and the bottom not at all. Their tent was pitched 250 feet from the edge of the crater, and during a violent squall the india-rubber floor of the tent was found to be on the point of melting, a *maximum* thermometer showing a temperature of 110 degrees on one side of the tent and of but 50 degrees on the other; in the middle it was 75.5 degrees. Outside it was intensely cold, and a thermometer on the tent cord showed a *minimum* of 13 degrees. At night they had a fine view of the crater, which has from a diameter north to south of 2000 ft., and from east to west of about 1500. ft. In the interior the walls descend to the bottom in a series of steps of precipice, and slope a good thousand feet, and at the bottom there was a nearly circular spot of glowing fire, 200 feet in diameter. On the sides of the interior, higher up

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fissures, from which flickering flames were leaping, showed that the lava was red hot a very short distance below the surface. The height he found to be 19,600 feet. The party remained at the top for twenty-six consecutive hours, sleeping about 130 feet below the loftiest point. At first they had felt the effects of the low pressure of the atmosphere, and again, as at Chimborazo, took chlorate of potash with good effect. All signs of mountain sickness had passed away before they commenced the descent, and did not recur during the journey. Nearly five months later Mr. Whymper returned to Chimborazo, and from a second reading of the barometer at 14.028 inches, with a temperature of 15 degrees Fahrenheit, he made the height 20,489 feet, the mean of the two readings giving 20,517 feet. While on the side of Chimborazo he witnessed a magnificent eruption of Cotopaxi, ashes rising in a column 20,000 feet above the rim of the crater and then spreading over an area of many miles. Prof. Bonney had submitted the ash to microscopic examination, and found that the fineness varied from 4,000 to 25,000 particles to the grain in weight, and from observation of the area over which the ash fell Mr. Whymper calculated that at least two million tons must have been ejected in this one eruption.

A TELEGRAM was read at a recent meeting of the French Academy of Sciences from M. de Brazza, who has been conducting an exploration in the region of the Ogowe and Congo, West Africa. Quite recently a French station has been founded in the upper course of the former river in connection with the International African Association. In July last, M. de Brazza informs the Academy he reached the Congo from this station on the Ogowe, between the river Inpaka Mpania and the river "Lawson Afrisi." Gaining the favor of King Makoko he pacified the tribes on the right bank of the Congo, and peacefully descended the river in a canoe. On October 8 he founded the station of Ntamo Ncoma on land ceded by King Makoko on the right bank of the Congo. M. de Brazza surveyed the route between the Ogowe and Congo; it is twelve marches in length, over a plateau of an average height of 800 meters. The country is healthy, and the population dense and peaceful. In November last M. de Brazza arrived at Mdambi Mbongo, the advanced post of Mr. Stanley, whom he met, and with whom he reached the latter's headquarters at Vivi on November 12. If the new station can be maintained and victualed, it is no doubt well chosen as a starting point for further discovery, for both north and south of it, there are large regions of which he knew nothing.

AT the meeting of the Geographical Society on Monday last, Mr. E. Delmar Morgan gave some account of his journey last year to Semiretchia and the town of Kulja. Being unable to make use of the more southern line of communications, Mr. Morgan traveled by the northern post road from Orenburg to Troitsk and Petropaulofsk, and thence to Omsk and Semipalatinsk. He then struck southwards to Sergiopol, where he was detained three weeks owing to the southern road being blocked by snow. He afterwards went to Kulja for a short time, and he also made some excursions to Issyk-kul and other places of interest. In the course of the discussion which followed the paper, Mr. Ashton Dilke, the only other Englishman who has visited Kulja, gave an interesting account of his experiences in that region a few years back.

M. TARRY, a member of the French Commission for Trans-Saharan Communications, is stated to have discovered in the south of Wargla the ruins of a large city called Cedrada, which had been entombed by sands of the desert. This city is placed in the Valley of Wed Mya, and in the vicinity of a number of sources which in former centuries watered thousands of palm trees. Orders have been sent to procure a set of sounding apparatus, and it is expected a large quantity of pure water will be extracted from the earth. M. Tarry published an appeal to the local papers in order to obtain from the Government the foundation of a colony in this remote region.

SANITARY HOUSES.—The Society of Arts propose to award medals for plans showing the best sanitary arrangements in houses built in the metropolis, such plans to be exhibited in the Society's rooms, Adelphi, in June, 1881, and to be sent in on or before 12th May, 1881. One silver medal will be awarded for the best sanitary arrangements carried out and in satisfactory working in a house let out in tenements to artisans for which a weekly rental is paid. One silver medal for the best sanitary arrangements in actual satisfactory working in a house of the yearly rental of from £40 or less to about £100 in value. One silver medal for the best sanitary arrangements in actual satisfactory working in a house of the yearly rental of £200 and upwards to any amount. The houses must be open to the inspection of the judges, who, in considering their award, will be guided by the suggestions of plans for main sewerage, drainage and water supply, made under the Public Health Act, 1875. The houses must have been in actual occupation within the last three months, and a certificate must be given by the occupiers, on a printed form, stating the satisfactory working of all the sanitary arrangements, such form to be obtained at the Society of Arts. The houses may be old, fitted with modern sanitary arrangements, or may be new. They must be within the metropolitan area of the Board of Works. The sanitary arrangements must include the conditions for good water supply, drainage, warming and ventilation of the house, and precautions taken against frost. The medals may be awarded to the occupiers of the houses or the lessees, or the owners. The plans must consist of a ground plan and sections, to the scale of not less than 1 inch to 5 feet; details not less than 1 inch to the foot. The plans may be accompanied by specifications.

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VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CXLX.—JUNE, 1881.—VOL. XXIV.

A RATIONAL SYSTEM OF PISTON PACKING.

By S. W. ROBINSON, C. E., Professor Mechanical Engineering, Ohio State University, Columbus.

Read before the American Society of Mechanical Engineers, May Meeting, Hartford, Conn.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE primary object of a good piston packing is evidently to prevent the working fluid from escaping past the piston. The sole object of the present paper is to investigate how this can be done most efficiently; leaving out of the question all such uses of packing as making it serve the purpose of a carriage for support of the piston, &c.; except, perhaps, a reference to this matter of carriage support—in that it seems desirable to have a carriage for the piston, especially in horizontal engines, and where the cylinder has been bored out larger than the piston to correct irregular wear after some use. But a glance at the matter will show that for the packing to serve as carriage, it must be very wide in order to present the necessary wearing surface for durability, and that where the packing is wide, the rims of the piston must be correspondingly narrow, and be accordingly unfitted for bearing the weight of the piston; and that the flexibility of the packing rings will allow them to take a somewhat irregular form, thus tending to wear the cylinder out of round; and that the devices for setting out the rings may change in intensity of action so as to cause the piston to ride upon the cylinder at some side, causing relatively rapid wear of the narrow rims of piston; and that the piston rod will thus be brought into wearing contact against its packing glands; and that in view of these facts it may be desirable to introduce a groove containing a solid, stout half ring about at the middle of the face of piston to serve as a carriage, with the piston properly jacked upon it: and, finally, that all these devices may be replaced by a considerable breadth of piston rims for support of piston, and narrow packing rings under outward pressure to prevent escape of working fluid. This is all the more evident when we reflect that the piston may be made light—hollow, if necessary, for this end, and the weight added to the cross head or the connecting rod—in which event the piston and cylinder will be subjected to the least possible wear, and thus scarcely need re-boring within the life of the engine. It is evident that this result is preferable to that where the cylinder frequently gets out of form to the extent necessitating repeated re-boring, when the lifetime of the engine will be more or less afflicted with "piston blowing."

Hence, it is proposed, here, to adopt as light a piston as possible, to use very narrow packing rings, and wide rims on the piston, especially for horizontal engines. The simplest possible packing consists of a single ring split upon one side. The simplest piston is one in a single piece, possibly cast hollow for securing desirable form. Hence, a sin-

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gle ring, sprung into a groove turned on the face of such a piston, combines the elements of simplicity. Two or more rings may, however, be used on a single piston, each sprung into its own groove.

We will now investigate the single-ring packing. It will appear afterwards that, to set the ring out by pressure of the working fluid transmitted to the underside of the ring through holes, causes excessive frictional contact of the ring upon the surface of cylinder. It would seem desirable, therefore, to give the ring its pressure of contact by means of the inherent stiffness of the ring itself, by turning it larger than the cylinder bore.

A ring, split upon one side and pressing outward with a constant pressure, as it evidently should for greatest efficiency, will necessarily be thicker at points opposite the split, as shown in Fig. 2.

FORM OF PACKING RING.

To find the law of varying thickness, let AB, Fig. 1, represent a piece of such a packing ring, the end or split being at

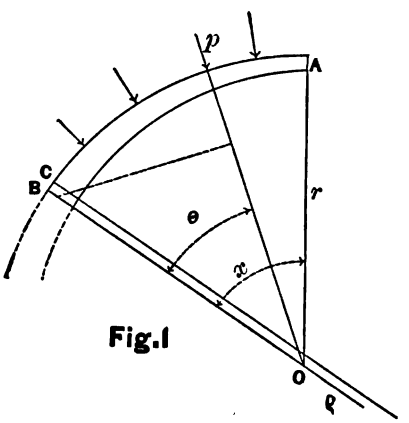

Fig. 1

A. Then the normal pressure of the ring against the cylinder along the outside of AB will be due to a flexural moment, or resistance to bending, of the section of ring at B. This, according to the theory of flexure, will be

$$\text{Flexural moment at B} = \frac{EI}{\rho} \quad . \quad . \quad . \quad (1)$$

where E is the coefficient of elasticity of the material of the ring, I the moment of inertia of the section of ring at B, and ρ the radius of curvature due to the bending. This radius is not to be confounded with the radius of the ring. To define it clearly, draw a line parallel to BO and very near to B as at C. Suppose these lines fixed to the ring, and parallel before flexure. After flexure these lines will intersect at some point more or less remote from B, according to the amount of bending. The distance from B to the point of intersection is ρ. It is evident that if the ring is of circular form before flexure, and also after, ρ will be of constant length for all parts of the ring. As the ring is most conveniently made of circular form, and as it will be used in a circular cylinder, it is desirable that the thickness shall so vary as to realize this and make ρ constant.

According to the theory of flexure, the flexural moment must equal the moment of the applied forces. This latter will, in the present case, be the resultant moment of all the normal pressures on AB. Let P represent the normal pressure per unit of surface of the ring against the cylinder, and if b be the breadth of ring, the pressure per unit of length of ring will be Pb, and for a length $rd\theta$, the pressure will be $Pb.rd\theta$. The moment of this element will be $Pbrd\theta.r \sin\theta$ with reference to an origin of moments at B, where the origin is taken for eq. (1). The integral of this, for θ varied between the limits x and o, will give the total moment of the forces acting on the part AB, or

$$\frac{EI}{\rho} = \int_o^x Pbr^2 \sin\theta \, d\theta = Pbr^2(1-\cos x)$$

$$= 2Pbr^2 \sin^2\frac{x}{2} \quad . \quad . \quad . \quad (2)$$

P being regarded as constant.

Let z be the thickness of the ring at B. Then

$$I = \tfrac{1}{12} bz^3$$

and

$$\frac{EI}{\rho} = \frac{Ez^3}{12\rho} = 2Pr^2 \sin^2\frac{x}{2}.$$

At the middle of ring, or where AB = 180°, we have

$$\frac{Ez_1^3}{12\rho_1} = 2Pr^2$$

whence

$$\frac{z^3}{\rho} = \frac{z_1^3}{\rho_1} \sin^2\frac{x}{2} \quad . \quad . \quad (3)$$

an equation for the whole ring, and giving the relation between z, ρ and x; upon any one of which we may impose arbitrary conditions, the other two remaining mu-

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tually variable. If we make z constant, as would follow from turning the ring of uniform thickness, ρ would necessarily vary with x and be infinite at the split when the ring is in use. This would indicate no bending of the ring near the split, and hence the tip end would here bear heavily upon the cylinder, with a probable space of no contact for some distance back. The only useful supposition for x is that it shall remain variable. As pointed out above, considerations of convenience make ρ constant, and hence necessarily equal ρ_1. Hence we have

TABLE OF VALUES FOR LAYING OUT THE RING:

$\frac{x}{2}$	$\sin\frac{x}{2}$	$z=\sin^{\frac{3}{2}}\frac{x}{2}$
5°	.087	.197
10	.174	.311
20	.342	.489
30	.500	.630
40	.643	.745
50	.766	.837
60	.866	.908
70	.940	.960
80	.985	.990
90	.1	.1

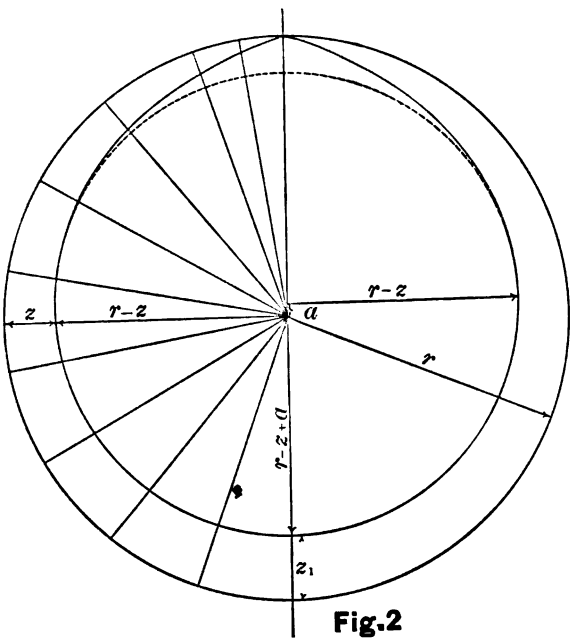

Fig.2

$$z^{\frac{3}{2}}=z_1^{\frac{3}{2}}\sin^3\frac{x}{2} \quad . \quad . \quad . \quad . \quad (4.)$$

for the final equation expressing the law of thickness, z, of ring.

It appears from the equation that the relation between z and z_1 is independent of the radius of the cylinder, and of the pressure of ring against the surface of cylinder. Hence, taking $z_1=1$, a table can be computed for the values of z, by which a ring for any cylinder can be drawn. Then, when the particular value of z_1, for any practical case, is found to be other than 1, the values of z are to be proportionately modified. Making $z_1=1$, we find the following

By these values the ring is drawn in Fig. 2 to a scale. The outside is taken, the circle of the cylinder into which the ring is supposed to be compressed when ready for service.

From this drawing it is found by placing one leg of a pair of dividers a distance, a, toward the split of the ring, and swinging the other leg about near the inside edge of ring, that about $\frac{2}{3}$ of the inner line of ring lies almost exactly on the arc of a circle, and with its center at a certain distance, a, from the center of the exterior of ring. The distance of this center from the inner surface of ring opposite split is $r-z_1+a$, the radius of the inside circle of ring.

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At the intermediate point of 90° from the split, this center is at a distance

$$r-z=r-z_1 \sin^{\frac{3}{2}} 45°$$

from the inner surface of ring, which is also the radius of the inside circle. Making these distances equal, we find

$$r-z_1+a=r-z_1 \sin^{\frac{3}{2}} 45°$$
$$a=z_1(1-\sin^{\frac{3}{2}} 45°)$$
$$a=0.206\, z_1 \text{ nearly} \quad . \quad . \quad (5)$$

If it be assumed that this circle gives the inner form of the ring with a sufficient degree of exactness, for about $\frac{2}{3}$ its extent, the ring can be formed in a turning lathe complete, except for the $\frac{1}{3}$ of inside surface, a half which is on each side of split. This could be dressed off subsequently. The lathe work would then most conveniently consist of mounting upon a face plate, or in a chuck, acylindric shell long enough to make several rings, with a stay of cross arms. The inside is to be first bored deep enough for several rings, and then the ring offset to the eccentricity $a=.206\, z_1$, and the outside turned off. The rings are then to be cut off with such breadth as desiried. The eccentricity is observed to be a little over $\frac{1}{3}$ the greatest thickness of ring.

In practice the tip ends of the ring at the split should be lapped a little, instead of being as shown in Fig. 2. A suitable way of doing this is shown in Fig. 3. For a perfect and complete stop

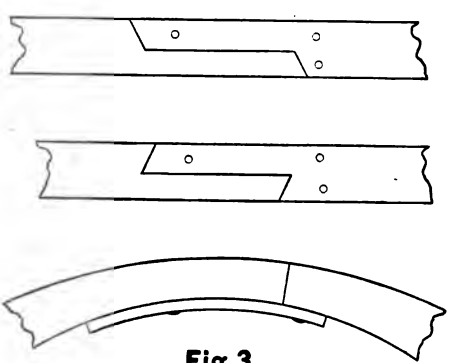

Fig.3

to the working fluid by ring, a strip should be riveted upon the under side of one tip so as to lie close to the under side of the other tip when in place, as shown. Otherwise, when the ring has worn so as to separate a little at the tips, the working fluid may enter between the tips at one side, pass under the ring to the opposite side, thence out and escape. It is evident that, for thus lapping the tips, the thickness, to that extent, should be constant, and not vary as in Fig. 2. To adjust the bearing of the lapping part against the cylinder, it is plainly necessary to dress off a trifle of the over-lapping tip outside, to compensate for the increased stiffness due to the deviation from Fig. 2, to a uniformity of thickness. The extent to which the tips may be made to overlap, as in Fig. 3, for a given excess of diameter at which the ring may be turned, will be considered subsequently.

OUTWARD PRESSURE OF RING.

It is evident that the outward pressure of the ring against the inside surface of cylinder will depend upon the diameter of the ring, its thickness, and the excess in diameter being given it when turned.

Let A be the center of the ring when turned to the radius r_1, and B the center when it is compressed into the cylinder of radius r_1. Let DC be a small part of that ring, so that

$$DC=rd\theta=r_1 d\theta'=\rho\, d\theta'' \quad . \quad . \quad . \quad (6)$$

ρ being the radius of curvature due to the bending or compressing of the ring,

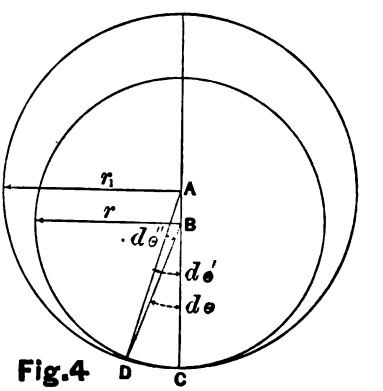

Fig.4

to change it from r_1 to r, Fig. 4, makes it evident that

$$d\theta''=d\theta-d\theta' \quad . \quad . \quad . \quad . \quad (7)$$

By aid of (6) and (7) we may write

$$\frac{d\theta-d\theta'}{d\theta}=\frac{r_1-r}{r_1}=\frac{d\theta''}{d\theta}=\frac{r}{\rho}$$

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whence $$\frac{r}{\rho}=\frac{r_1-r}{r_1} \quad . \quad . \quad . \quad . \quad (8)$$

But as a constant value of ρ has been adopted, $\rho=\rho_1$, and hence, combining (8) with the equation preceding (3), we have

$$\frac{Ez_1^3}{12}\cdot\frac{r_1-r}{r_1 r}=2Pr^3$$

whence the amount of normal pressure of ring per square unit is

$$P=\frac{E}{24}\cdot\frac{z_1^3}{r^3}\cdot\frac{r_1-r}{r_1}.$$

Hence, it appears that the intensity of pressure of ring upon cylinder will vary directly as the cube of the thickness, and nearly as the excess of diameter at which the ring is turned.

This excess in external diameter, of ring over the cylinder bore, is arbitrary. But in assuming the excess, probably no one would take the mean diameter of ring, inside and outside, less than that of the cylinder bore. A little consideration would probably fix it larger. If we adopt such a relation that $\frac{2}{3}$ of the ring will be outside the groove when first sprung into it, we have

rad. of piston, $r=r_1-\frac{2}{3}(r_1-\text{inside rad.})$.

But inside rad. $=r_1-z_1+a=r_1-.794\,z_1$

$$\therefore\ r=r_1-.529\,z_1$$

$$\therefore\ \frac{r_1-r}{r_1}=\frac{.529\,z_1}{r_1}=.5\,\frac{z_1}{r}\text{ nearly.}$$

Hence $$P=\frac{E}{48}\,\frac{z_1^4}{r^4} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

TENDENCY OF FLUID TO LIFT THE RING.

In a thin space between the ring and cylinder, the fluid will flow, as shown in Fig. 5, from p_1 to p_2, the frictional resistance of an inelastic fluid like water in the space t, hindering the flow, and giving cause, for pressure upon ring; and in elastic fluids, like air, both the frictional resistance and expansive pressure in the space, t, between ring and cylinder, will have a combined effect to press the ring back, and to increase the space for escape.

1. *Case of Ordinary Water Pump.*— Here the density does not sensibly change between p_1 and p_2. In this case

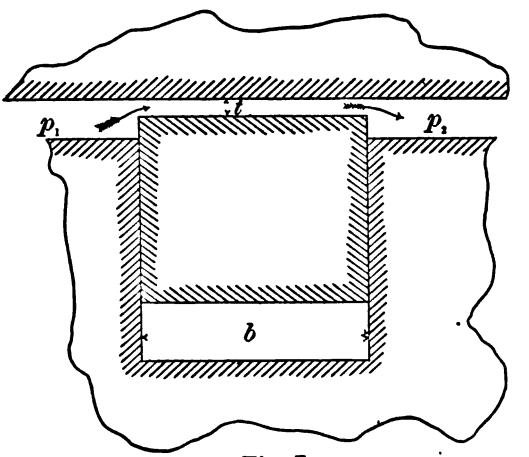

Fig.5

the velocity of flow will be constant within the space t, and the reduction of pressure will be in two parts; first, for acceleration at entry to the space, and second, for frictional resistance along the space. According to an article which I have lately published in VAN NOSTRAND'S ENGINEERING MAGAZINE (see p. 372),

$$h'+h''=h=\frac{v^2}{2gu^2}+\frac{fsl}{a}\frac{v^2}{2g}=\frac{p_1-p}{d}+\frac{p-p_2}{d}$$

or $$p_1-p=\frac{\delta v^2}{2gu^2} \quad . \quad . \quad . \quad . \quad (10)$$

for entry, and

$$p-p_2=\frac{\delta fsl}{a}\,\frac{v^2}{2g} \quad . \quad . \quad . \quad (11)$$

for the space t, in which v is the velocity in the space, u the coefficient of velocity for the orifice of entry, here about 0.85;

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δ the weight per unit of volume of the flowing fluid; a, the sectional area, transverse to the flow, of so much of the space t as is considered; s, the perimeter of the same section; f, the coefficient of friction of the fluid against the ring or cylinder; $l=b$, the length in the direction of motion of the flowing sheet, or breadth of ring; and p, the absolute pressure of fluid just within the entrance to the space t. The pressure will gradually decrease, from p to p_2, as the fluid passes along the space t. If x be taken for the distance from the p_2 side of ring, we have

$$p-p_2=\frac{\delta f s x}{a}\frac{v^2}{2g} \quad . \quad . \quad . \quad (12)$$

where p will now be the pressure of fluid in the space t at the distance x. This pressure tends to push the ring back, and it being variable, the total amount of it for the whole breadth, b, of ring and for a unit's length along the ring, will be,

$$\mathrm{P}b=\int_0^b p\,dx=\int_0^b\left(\frac{\delta f s}{a}\frac{v^2}{2g}x+p_2\right)dx \quad . \quad (13)$$

$$=\frac{\delta f s}{a}\frac{v^2}{2g}\frac{b^2}{2}+p_2 b=(p-p_2)\frac{b}{2}+p_2 b$$

by eq. (11). Hence

$$\frac{\mathrm{P}}{p_2}=\tfrac{1}{2}\left(1+\frac{p}{p_2}\right) \quad . \quad . \quad (14)$$

and numerically for

$\frac{p}{p_2}=2$	$\frac{\mathrm{P}}{p_2}=1.5$
4	2.5
6	3.5
8	4.5
10	5.5

(A)

an expression giving in terms of the pressures of fluid at opposite edges of packing ring, the ratio of the total pressure tending to push the ring away from the cylinder to the pressure at the exhaust side of piston. These pressures are per square unit of area absolute. A noticable fact is that this ratio is independent of the breadth of ring, of the density of fluid, and of the coefficient of friction, except so far as p may depend upon them. That p will not coincide with p_2 is evident from (10).

To find the relative proportions of fall of pressure due to (10) and (11), we may take their ratio. Hence

$$\frac{p_1-p}{p-p_2}=\frac{a}{fsbu^2}=\frac{t}{2fbu^2} \quad . \quad . \quad . \quad (15)$$

in which $$\frac{a}{s}=\frac{t}{2}$$

since for a given extent, k, along the ring

$$a=kt \quad s=2k.$$

Hence, the fall of pressure varies only with t and b, the thickness of space and length of flow between ring and cylinder. But it will, of course, be desirable that t be very small, far within the hundredth part of an inch. If, for example, it be taken in thousandths of an inch, we have for $f=.006$, $b=.5$ and $u^2=.7$

$t=1$ thousandth	$\frac{p_1-p}{p-p_2}=$	.238
2 "		.476
4 "		.952
8 "		1.904
1 hundredth		2.381

(B)

Hence, with a thickness of space t, of a little over 4 thousandths of an inch, half the fall of pressure from p_1 to p_2 will be consumed in entering the fluid into the space t. As the thickness of this space thus appears to be an important element in determining $\frac{\mathrm{P}}{p_2}$ and consequently the thickness z_1 of ring, the latter diminishing with P, it becomes desirable to determine the admissible limits of t. This is to be done by aid of the equation just preceding (10), whence the velocity of escape is found by

$$v^2=\frac{p_1-p_2}{\delta}\cdot\frac{2g}{\frac{1}{u^2}+\frac{2fb}{t}} \quad . \quad . \quad . \quad (16)$$

The percentage of the whole piston displacement in the volume escaping past the piston will be

$$\frac{q}{\mathrm{Q}}=\frac{v\times\text{area of whole space } t}{\text{piston displacement}}=\frac{v\times 2\pi r t}{\pi r^2\mathrm{V}}=\frac{2vt}{r\mathrm{V}}$$

where V is the piston speed in ft. per sec.

Combining this with (16) by eliminating v, and we obtain,

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$$\left(\frac{q}{Q}\right)^2=\frac{\frac{8gt^2}{r^2V^2\delta}\left(\frac{p_1}{p_2}-1\right)}{\frac{1}{u^2}+\frac{2fb}{t}} \quad . \quad (17)$$

If it is desired to take account of the effect of the motion of piston and of packing ring, upon the actual velocity of fluid escape, we find the latter to be,

$$v-\frac{V}{2}$$

and then the first member of (17) should be

$$\left(\frac{q}{Q}+\frac{t}{r}\right)^2$$

This may be put in a more convenient form by factoring and tabulating a part. Thus, if $d=2r=$ diam. of piston,

$$\frac{q}{Q}+\frac{2t}{d}=\frac{1}{Vd}\sqrt{\frac{p_1}{p_2}-1}\,(\text{Tab.val.}) \quad (18)$$

where, for water pump rings, of a width $b=.5$ of an inch, and for $t=1, 2, 5, 10$, thousandths of an inch.

Tab. val. $=.0057\ .014\ .0480\ .1092$ (C.)

For these values p_2 is taken at one atmosphere.

To obtain an idea of the practical values of (18), we have, for a piston speed of pump piston of $V=2fi$ per sec.,

$d=\frac{1}{2}$ ft., or $Vd=1$, and $\frac{p_1}{p_2}$ in atmospheres.

For t in inches. =	1	2	5	10 [thousandths
$\frac{p_1}{p_2}=2,\ldots.\frac{q}{Q}=$	.005	.010	.048	.109 (D)
" $=8,\ldots.$ " $=$	.015	.027	.127	.288

the term $\frac{2t}{d}$ being inconsiderable.

As the maximum admissible leakage of piston would probably be assumed from 1 to 5 per cent. of piston displacement, it appears that the greatest admissible thickness of space, t, is about 2 thousandths of an inch in pumps.

This thickness, compared with the table of values for eq. (15) indicates that we may count on

$$\frac{p_1-p}{p-p_2}=\text{not greater than } o \text{ to } .5.$$

or the fall of pressure on entering the space t, should not exceed a half of the fall due to passing the ring; or, it should not exceed a third of the total fall from p_1 to p_2. In other words, the fall of pressure, $p-p_2$, in passing the ring, should not be less than two-thirds of the total difference p_1-p_2 of pressure on opposite sides of piston.

To illustrate further, let the pump be working where

$\frac{p_1}{p_2}=6$ and $\frac{2}{3}$ of this, gives $\frac{p}{p_2}=4$.

Then the table for eq. (14) gives

$$\frac{P}{p_2}=2.5 \text{ for } \frac{p}{p_2}=4;$$

and this, combined with eq. (9), gives

$$2.5p_2=\frac{Ez_1^4}{48r^4}.$$

If $p_2=1$ atmosphere$=15$ lbs. per sq. inch, and if the ring be made of cast iron, as probably a good material, when $E=20{,}000{,}000$. Then

$$\frac{z_1}{r}=.097.$$

If the pump has a 12" cylinder

$$z_1=.584 \text{ inch}$$

so that for the conditions assumed, a 12-inch piston packing ring for a pump will be about $\frac{2}{3}$ of an inch thick at the thickest place.

The eccentricity, a, for use in turning the ring will be

$a=.206z_1=.12$ inch, or about $\frac{1}{8}$ of an inch.

These results are for a pump where the pressure p_2, on the suction side of piston, is one atmosphere; and p_1, on the pressure side, six atmospheres.

For similar conditions, except the working pressure $p_1=2$ atmospheres, we have

$z_1=.496$ inch, or about half an inch.

$a=\frac{1}{10}$ inch.

It is noticeable, from eq. (9), that z_1 is proportional to r for a given pressure, so that the thickness of ring for other sizes than 12" pistons, can readily be obtained.

If we ignore the refinements about the orifice of entry, and assume p as identical with p_1, we only require formulas (14) and (9) to determine the ring. In fact, they may be combined, giving

$$\left(\frac{z_1}{r}\right)^4=\frac{24p_2}{E}\left(1+\frac{p_1}{p_2}\right) \quad . \quad . \quad . \quad (19)$$

Values of z_1 computed by this for the

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above examples give .636 and .515 respectively, in place of .584 and .496 as corrected for the orifice of entry.

These differences being comparatively unimportant, the effect of orifice of entry will be ignored in the following cases:

2d. *Case of an Elastic Fluid like Air.*—Here the flow will be at some intermediate condition between the adiabatic and isothermal for the gas while escaping the packing ring. Considering it adiabatic, the proper expression taken from the article previously referred to, is:

$$\frac{fs}{a}\frac{v_2^2}{2g}\,b=\frac{\gamma}{\gamma+1}\,\frac{p_2}{\delta_2}\left\{\left(\frac{p_1}{p_2}\right)^{\frac{\gamma+1}{\gamma}}-1\right\}$$

where v_2 is the velocity of escape and p_2, and $\gamma=1.408$ for a perfect gas. For the present case this eq. may be put under the following form:

$$Ab=\left(\frac{p_1}{p_2}\right)^{\frac{\gamma+1}{\gamma}}-1 \quad . \quad . \quad . \quad (20)$$

or for shorter distances, x, reckoned from the exit side of ring where also the pressure will be p, we have

$$Ax=\left(\frac{p}{p_2}\right)^{\frac{\gamma+1}{\gamma}}-1$$

or

$$(1+Ax)^{\frac{\gamma}{\gamma+1}}=\frac{p}{p_2}$$

The value of p from this, introduced into eq. (13) and integrated, gives

$$Pb=\frac{p_2}{A}\,\frac{\gamma+1}{2\gamma+1}\left((1+Ab)^{\frac{2\gamma+1}{\gamma+1}}-1\right).$$

Restoring the value of A by aid of (20) we obtain

$$\frac{P}{p_2}=\frac{\gamma+1}{2\gamma+1}\left\{\frac{\left(\frac{p_1}{p_2}\right)^{\frac{2\gamma+1}{\gamma}}-1}{\left(\frac{p_1}{p_2}\right)^{\frac{\gamma+1}{\gamma}}-1}\right\} \quad . \quad . \quad . \quad (21)$$

an expression in terms of p_1 and p_2 only. Hence a table is readily computed for practical use, thus:

If $\frac{p_1}{p_2}=4$	$\frac{P}{p_2}=2.72$	
6	3.94	(E)
8	5.18	
10	6.42	

By employing these values of P in (9), the thickness of ring, z_1, can be calculated.

If the flow past the ring be regarded as isothermal, γ, in equation (21) is to be taken equal 1, and hence

$$\frac{P}{p_2}=\frac{2}{3}\left\{\frac{\left(\frac{p_1}{p_2}\right)^3-1}{\left(\frac{p_1}{p_2}\right)^2-1}\right\} \quad . \quad . \quad . \quad (22)$$

and hence the following table:

If $\frac{p_1}{p_2}=4$	$\frac{P}{p_2}=2.80$	
6	4.09	(F)
8	5.41	
10	6.73	

These values of P differ only slightly from those in (E), so that as regards the pack-ring question, since the 4th root of these quantities is to be taken in (9), the difference for the adiabatic and isothermal condition is entirely insignificant. Even compared with the table (A) for pump-packing rings, the 4th root will differ but slightly for a given ratio of pressures p_1 and p_2.

Hence, the following table will be found to cover nearly the whole range of practice:

PRACTICAL TABLE FOR SINGLE RING PACKING.

		Pumps.	Engines, &c.
For $\frac{p_1}{p_2}=4$	$\frac{z_1}{r.p_2^{\frac{1}{4}}}=$	.0495	.0509
6		.0538	.0560
8		.0573	.0600
10		.0603	.0634

p_1 = higher absolute pressure, lbs. per square inch, on piston.
p_2 = lower absolute pressure, lbs. per square inch, on piston.
r = radius of cylinder bore, in inches.
z_1 = thickest place in the packing ring, in inches.
Eccentricity of a ring $=a=z_1$ .206.

The ring is supposed to be turned so that when sprung into its groove, $\frac{2}{3}$ of it will lie outside of the groove before the piston is put into the cylinder. This is realized by making the outside diameter of ring when turned =

$$d_1=d+z_1 \text{ nearly}$$

where d = the diameter of cylinder bore

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The inside diameter, d_2, at which to bore out the ring will be $2(r-z+a)$, or

$$d_2 = d_1 - 1.588\, z_1$$
$$= d_1 - 1.6\, z_1 \text{ nearly.}$$

The groove for the ring is to be turned out on the solid face of the piston, the depth being somewhat greater than the thickest place z_1 of ring.

The width of the groove should be such as to give an accurate free fit to the ring.

The width of ring is arbitrary, the above formulas (9), (14), (21) and (22) for determining the ring, not containing any term for breadth. The total pressure of ring against the cylinder is proportional to the width for a given thickness. Hence, the pressure per square inch of surface is constant. The rate of wear of the ring from its surface will be proportional to the pressure per square inch. Hence, a wide ring will wear no longer than a narrow one. A wide ring will, however, wear the cylinder bore more than a narrow one, and also leave narrower rims on the piston for wear. Hence, as a narrow ring is, according to the formulas, as efficient in preventing the escape of the working fluid as a wide one, it is decidedly best to adopt a narrow ring, usually not to exceed a half an inch.

In forming the lap shown in Fig. 3, a portion of the ring must be cut away. The demand for this is met in the ring being turned larger than the cylinder, thus requiring some to be cut from it.

According to directions above, the excess in diameter over the cylinder bore, at which the ring is turned is z. If the ring did not elongate along its exterior surface as it is sprung into the cylinder, we would find the amount to cut out $= \pi z_1$, since the outside lengths of the ring, before and after, would be $\pi d_1 = \pi (d + z_1)$ and πd, the difference of which is πz_1. But as the outside elongates slightly in the flexure, we find by considering the amount of flexure, position of the neutral axis, &c., that the amount to cut

$$\text{from the ring} = \pi z_1 \left(1 + .397 \frac{z_1}{r}\right)$$

In regard to setting the ring out by pressure of working fluid beneath it, introduced through holes from the pressure side of piston, it is evident that the pressure of ring upon cylinder per square inch will be nearly p_1, while the above figures make it P. The former pressure, as seen by tables (A), (E) and (F), is about 50 per cent. greater than the latter, showing that the so-called steam packing is to that extent too heavily set,

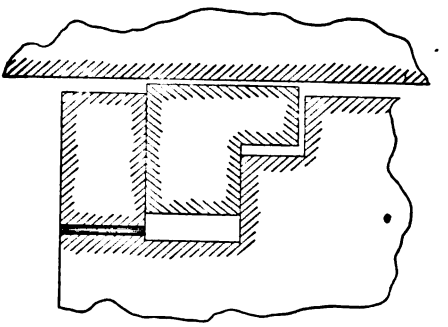

Fig.6

causing undue wear, resistance, &c. The steam-packing ring should, therefore, be made as in Fig. 6, with pressure under only a part of it, the wing being relieved to prevent receiving pressure.

When several rings are employed on one piston each might be so designed as to act for reducing only part of the pressure, and the rings could be made somewhat thinner than where one is depended upon for making the joint. The "practical table," however, indicates only a reduction in thickness of from a fourth to a third.

THE construction of the St. Gothard Railway, on the Tunis side, is now, the Geneva correspondent of the *Times* says, in so forward a state that the completion of the section between Airolo and Bellinzona by the end of June is regarded as certain. The section between Bellinzona and Locarno has been in running order for some time. Owing, however, to the condition of the great tunnel, where the so-called windy stretch, a bed of rotten limestone and gypsum, which swells on exposure to the air, is still breaking the engineers' hearts, the line is not likely to be ready for through traffic before October, if then. The Federal tribunal have decided against the contractors for the great tunnel in respect of their demand for a prolongation by 780 days of the time fixed for the completion of the work.

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THE METRIC SYSTEM.

From the Proceedings of the Boston Society of Civil Engineers.

THE Committee* on the Metric System of Weights and Measures presents this report in obedience to the vote passed at the last annual meeting, March 17, 1880, that "The Committee on the Metric System shall gather, from time to time, and present to the Society, all attainable information relative to the progress toward the introduction of the metric system into this country and the world at large."

FOREIGN COUNTRIES.

As for the world at large, its chief nations, as they have emerged from the barbarous state of warring tribes, have passed laws (as the United States has done) to make weights and measures uniform throughout each nation's domain. Now that international communication has been so enormously developed—that it is easier than was communication between different parts of the same nation at the beginning of this century, there is exactly the same occasion for laws establishing international uniformity. Among foreign nations the progress in this direction during the past year has consisted chiefly in the execution of laws previously enacted for the adoption of the metric system.

In Sweden, for instance, the beginning of 1881 is the time that was fixed for its use to become obligatory, for customs and postal purposes, and for railroad transportation as was stated in the report of the chief clerk of the United States Treasury Department, dated March 26, 1878.

In Switzerland, the latest information contained in that report showed that the use of the pure metric system was optional, side by side with an old compromise system; it has now been made obligatory. The attention of some patriots in the United States is invited to the fact that this change was accomplished without bloodshed, and that Switzerland still maintains a republican form of government.

In German handbooks of mechanics, Mr. Coleman Sellers states that formulas used to be expressed both in meters and in Prussian inches, but that with the year 1880 the inch was dropped whereever possible.

From Greece, a merchant of this city has recently imported wine in liters, whereas a few years ago it came in old measures.

More important to us is the following, quoted from the "Railroad Gazette" of July 9, 1880: "The metric system, on the 15th of July, becomes obligatory in the kingdom of Spain and all its colonies, including Cuba, with which our commercial relations are very intimate. The Turkish government has also ordered the introduction of this system into all its provinces, including Tripolis and Arabia. The cubit gives way to the meter in Jerusalem, and the shekel to the kilogram."

The significance of this lies in the fact that from Cuba, Porto Rico, and other Spanish possessions come about one-sixth part of our imports. Before this change our imports from Great Britain and her colonies were of nearly the same value as our imports from all countries where the metric system is established; the addition to the latter class of our imports from the Spanish colonies will make that class include about fifty per cent. more than the value we import from Great Britain and the British possessions, and will make it amount to more than than half the total imports through the custom houses of the United States.

NOTE.—The following table of our imports from foreign countries, grouped according to their metric legislation, for the year ending June 30, 1877, is taken from the report already mentioned of the chief clerk of the Treasury Department, with the single change of the Spanish possessions from the class of countries where the metric system is legalized to that where its use is obligatory. Austria, Turkey, Sweden and

*The Committee was composed of Fred. Brooks, L. Frederick Rice, and Clarence W. Lunt.

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Norway are left just where he placed them about three years ago:

METRIC SYSTEM OBLIGATORY.

Argentine Republic	$3,449,559
Belgium	5,079,149
Brazil	43,498,041
Chili	698,716
France and French possessions	52,862,387
Germany	33,035,485
Greece	523,128
Italy	7,105,366
Mexico	15,444 583
Netherlands	2,547,119
Peru	1,545,461
Portugal	524,828
Roumania	—
San Domingo	560,709
Spain	3,280,836
Spanish possessions (Cuba, Porto Rico, etc.)	79,544,185
Switzerland	—
United States of Columbia	5,454,393
Uruguay	2,197,711
	$257,351,654

METRIC SYSTEM LEGALIZED.

Great Britain and British possessions	$185,667,400

METRIC SYSTEM PARTIALLY IN USE.

Austria	$414,020
Azores, Madeira, and Cape de Verde Islands	92,351
Central American States	2,883,602
Denmark	9,053
Japan	18,689,438
Sweden and Norway	243,562
Turkey in Europe	46,714
	$17,378,735

METRIC SYSTEM NOT LEGALIZED OR IN USE.

Danish West Indies	284,480
Dutch East Indies	4,511,444
Dutch West Indies and Dutch Guiana	735,525
China	11,141,447
Greenland	137,465
Hawaiian Islands	2,631,763
Hayti	3,303,709
Liberia	57,470
Russia	618,534
Turkey in Asia and Africa	382,303
	$23,804,140

SUMMARY.

Imports from countries where the metric system is.	Obligatory	$257,351,654
	Legalized	185,667,400
	Partially in use	17,378,735
	Not legalized or in use	23,804,140
	Total	$484,201,929

In regard to the British item above, it should be observed that the British colonies do not all use the imperial weights and measures. Mauritius adopted the metric system a few years ago; in India its ultimate adoption is provided for by the Indian Weights and Measures Act, 1870, but various native units are now chiefly used. On the other hand, in some of the countries where the metric system has been made obligatory by law, its introduction has not yet been completely effected.

Another and more important observation is that the British capacity measures are incommensurable with those of the United States.

It might be added, paradoxically, that the United States standard of weight is very different from that of Great Britain, for in Prof. Hilgard's report on American Standards of Length, dated July 10, 1880 (being Appendix No. 12 to the Coast and Geodetic Survey Report for 1877), it is stated that "no enactment by Congress has ever been made, declaring particular measures in the keeping of the government as standards, except the standard troy pound of the Mint of the United States, at Philadelphia, procured in 1827," etc., but the troy pound has been abolished in Great Britain, as may be seen from the compulsory Weights and Measures Act, 1878, of the British Parliament. A point of real importance is that the British ton is fixed at 2,240 pounds, while the ton of the United States is a varying quantity and may be represented by x.

As there is some nonsense afloat about what is miscalled the "Anglo-Saxon" race, your committee remarks that the people of England gracefully submit to these "arbitrary" enactments made by their own chosen representatives in Parliament assembled.

UNITED STATES CUSTOM HOUSES.

As to legislation, the progress toward the introduction of the metric system into the United States may be gauged by the fate of the bill, H. R., No. 411, introduced in the present Congress, April 21, 1879. It provides that the *ad quantum* duties upon articles imported with metric invoices shall be assessed at metric rates, which, by throwing off awkward fractions, are made to favor very slightly the use of the metric system in invoices.

A year ago the American Metrological Society was circulating a memorial in fa-

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vor of such legislation. The memorial was printed in "Engineering News" of March 20, 1880. It was signed by fifty gentlemen out of eighty-eight, whose names are on the printed list of active members of the Boston Society of Civil Engineers, dated January, 1880. It was offered to twenty others, who did not sign it; and your committee does not know of its being presented at all to the remaining eighteen. This is believed to be the best test hitherto obtained (though an imperfect one) of the opinions of the individual members of this Society. The memorial was also signed by about six thousand other persons. A memorial against any further legislation to facilitate the introduction of the metric system has been circulated (but not in the Boston Society of Civil Engineers) by the International Institute for Preserving and Perfecting Weights and Measures. It was printed in "Engineering News" of April 10, 1880. From the same source another memorial to eradicate the metric system from the Coast and Geodetic Survey and other government offices is in preparation.

The following card, dated at Cleveland, April 12, 1880, was issued by Charles Latimer, the chief engineer of the New York, Pennsylvania and Ohio Railroad:

"As the active executive officer of the International Institute for Preserving and Perfecting Weights and Measures, I wish to warn the public, and especially mechanics and other workingmen, against the attempts now making to introduce the French metric system into this country by a compulsory Act of Congress. This is being done under false pretences, by wording their petitions for the people to sign, so as to convey the idea that they are asking for a decimal system of weights and measures in accord with our decimal system of money, when the measure they are trying to secure is the French metric system, pure and simple, with all its barbarous Greek and Latin names unknown to our people and illy adapted to our language. To accomplish this purpose, petitions to Congress, asking simply for a decimal system of weights and measures, as above stated, are being circulated, while the country is being flooded with books, pamphlets, and other publications on the subject, worded in the most specious and attractive style, so as to draw the most money from the unwary. The purchase of such documents is only a waste of money, tending to evil instead of good, making the rich richer and the poor poorer. Besides, many well-informed persons are strong in the belief that this whole movement is a deliberate attempt to subvert our republican government, to bring our people into a condition where such arbitrary measures can be forced upon them at the point of the bayonet, if need be."

In the Civil Engineers' Club of the Northwest, which has now been reorganized as the Western Society of Engineers, the following resolution, moved by Mr. Greeley, was adopted May 4, 1880, by a vote of sixteen to thirteen; six of the sixteen affirmative votes and eight of the thirteen negative votes were cast by letter ballot or proxy.

"*Resolved*, That in the opinion of this Club the substitution at some future time, to be hereafter determined, of the metric system of weights and measures for those now in use in the United States, is to be desired; and that as a step towards this change, we favor the recommendation made at the last session of the Forty-fifth Congress, and renewed at the special session of the Forty-sixth Congress, by the Committee on Coinage, Weights and Measures, of the House of Representatives, that an act should be passed requiring the use of the metric denominations of weight and measure in the custom houses of the United States."

During the first annual meeting of the American Society of Mechanical Engineers, Nov. 5, 1880, the following resolutions were offered by Mr. Henry R. Worthington (who has since died):

"*Resolved*, That this society deprecates any legislation tending to make the adoption of the metric system of measures obligatory in our industrial establishments;" also,

"*Resolved*, That the secretary be instructed to communicate the sentiments of this resolution to all concerned in procuring such legislation, and also to send a copy to the Anti-Metric Society of Cleveland."

A letter ballot was ordered to be taken upon these resolutions. Your commit-

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tee has not yet been honored with any copy from the secretary, as proposed, but presumes that sooner or later a ballot will be taken. Whatever be the result of this ballot, as a custom house is not considered an "industrial establishment," the world will remain in doubt as to what the Mechanical Engineers think about the government's using the metric system in the transaction of its own business of collecting specific duties upon such imports as are invoiced in meters and kilos.

A pertinent quotation, though several years earlier in date, may be made from the report of a special committee of the American Society of Civil Engineers relative to the memorials which the American Metrological Society addressed to a former Congress in behalf of the metric sytem. The report was signed by R. H. Thurston and J. J. R. Croes; it was presented to the American Society of Civil Engineers, May 6, 1874, and was laid on the table; the quotation is: "A series of legal enactments, carefully considered, cautiously introduced, and steadily pursued, is considered the proper, the wisest, and the necessary course to be pursued in the endeavor to attain these great benefits."

Bill H. R., No. 411, is still pending in the Forty-sixth Congress. The Committee on Coinage, Weights and Measures had printed, during the second session, Report No. 203, relating to coinage, and Mis. Doc. No. 29, containing Col. Thomas S. Sedgwick's scheme for decimalizing the foot and ounce, and abandoning the present inch, pound, and other units, together with a reply from Dr. Culver, the clerk of the committee, in advocacy of the metric system.

PROFESSIONAL USE.

In advance of any legislation to give people a definite idea at what time the change of standard is likely to be effected, the metric weights and measures are creeping into actual use; and the perpetual recurrence of references to it in the news of the day foreshadows its coming. Previous to our recent national election, a map was published showing the distribution of the party votes in the several Congressional districts, on a scale of 1,000 votes to a millimeter. The strength of the starving Dr. Tanner was reported in kilos in last summer's newspapers; P. T. Barnum advertised the number of square meters of canvas provided to shelter his great moral show; M. de Lesseps announced in our principal cities, in metric terms, his plans for an inter-oceanic canal. (It is not intended to class these gentlemen together in other respect.) Our manufacturers occasionally receive a foreign order in metric terms; and in some kinds of business there are special reasons which favor the adoption of the metric system; so to them we naturally turnin looking for the signs of progress.

Apothecaries, for instance, have intimate relations with the sciences of chemistry and medicine, and their partial separation from other kinds of business is illustrated by their having had an Apothecaries' Weight of their own. The 1880 edition of the apothecaries' pharmacopœia, to be published some time hereafter, will be changed toward the metric system, as your committee explained a year ago. The committee in charge of the publication met in Washington last May, and determined that the pharmacopœia shall state ingredients by proportion chiefly, and that when an absolute weight is mentioned, it shall be in grams, followed by an equivalent in grains; but that no pounds, ounces, drachms, scruples, or pennyweights shall appear. This will naturally tend to the practical adoption of the metric system by druggists and physicians, who constitute a large and influential part of our population.

Another old table different from the measure used in general business was Surveyors' Measure, in which 10 chains made 1 furlong, and the chain (equal to 22 yards) was divided into 100 links, each equal to 7.92 inches. Surveying, and especially railroad surveying, is now very extensively done with a chain $33\frac{1}{3}$ yards long, so that $6\frac{2}{3}$ such chains make 1 furlong; the subdivision is into 100 feet, and the foot is divided into tenths, each equal to $1\frac{1}{2}$ inches, and hundredths, each of which is 4 per cent. less than the eighth of an inch. This plainly indicates that surveyors are bound to have decimal subdivision, and that they are not bound to the customary inch and yard. Prof. H. F. Walling, a member of this Society, wrote from Ohio, where

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he was engaged in making county maps, under date of March 1, 1880: "My occupation here during the past year has more than ever made it apparent to me that, so far as land surveying and conveyancing are concerned, no great inconvenience would be experienced from an immediate change to the metric system, or, at most, but little more than continually arises from the existing variety of standards. It is very evident to me that the adoption of the metric system would very soon result in the saving of a vast amount of vexatious and unnecessary labor to all persons connected in any way with operations in land. . .

"I have frequently found deeds in which dimensions were given in chains and links, rods, feet and inches, and fractions of an inch, all in the same conveyance."

The meter has been made the unit of the triangulation of the New York State Survey, with regard to which your committee corresponded with the director, as reported four years ago.

Upon the charts of the Coast and Geodetic Survey metric linear scales have been printed, beginning with the report for 1876, issued during the year 1880. Your committee wrote to the superintendent in 1877, asking if there could be any objection to adopting this practice, and reported the fact to you Oct. 1877.

The Graphic Trigonometer, exhibited by Mr. Adams at the meeting of this society last October, was constructed to metric dimensions.

James W. Queen & Co. published, last year, continuous metric profile paper, with lines one millimeter apart. As this makes 25 lines to 1 inch, as nearly as such paper generally measures, it can be used, if desired, in connection with our old units. Its general adoption, by keeping the metric units before the eye, would tend to make the system familiar. The millimeter spacing is good, being midway between Plate A (20 lines to an inch) and Plate B (30 lines to an inch), both of which are already known to be convenient. It corresponds to Plate C. It is amusing to notice that this paper is sold by the *yard;* as it is already marked off according to the metric system, the time may come when it will be sold by the meter without remeasurement. The publishers state that they find an increasing demand for it; and they have just now published sheets of metric cross-section paper, with lines two millimeters apart, and every fifth and tenth line made heavier.

Several new tables containing metric equivalents have been published, the most noteworthy being "Molesworth's Metrical Tables," uniform with the same author's "Engineer's Pocket Book," and of conspicuous merit in many particulars, but based on the law of Great Britain, which differs from ours in two respects. The imperial capacity measures are entirely independent of ours; and Parliament has declared that a meter shall be taken as equivalent to 39.3708 inches, while our Congress has enacted that it shall be taken as 39.37 inches. The meter actually is 39.37043 inches, according to what is accepted as the best determination yet made. One of these is based on Captain Kater's determination for the old British yard destroyed by fire in 1834; one on Capt. Clarke's determination for the new British yard, established in 1855; the third is intended to be sufficient for business purposes without attempting scientific refinement. These differences of less than a thouaandth part of an inch are unimportant in commercial transactions, but are sufficient to produce some annoyance in computation, especially in square and cubic measure.

Another point in regard to which uniformity is desirable is the practice of abbreviation. The following system of abbreviations, as initiated by the Swiss government and approved by the government of Italy, has been decided upon by the International Committee of Weights, sitting at Paris. The "Bulletin du Ministre des Travaux Publics," and some other French publications, adopt it:

Length.....	Kilometer.....	km.
	Meter.....	m.
	Decimeter.....	dm.
	Centimeter.....	cm.
	Millimeter.....	mm.
	Mikron (0.001 mm)....	μ
Area.....	Square kilometer.....	km^2.
	Hektar.....	ha.
	Ar.....	a.
	Square meter.....	m^2.
	Square decimeter.	dm^2.
	Square centimeter.....	cm^2.
	Square millimeter.....	mm^2.

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Cubic measure..	Cubic meter	m^3.
	Stere	s.
	Cubic decimeter	dm^3.
	Cubic centimeter	cm^3.
	Cubic millimeter	mm^3.
Capacity	Hektoliter	hl.
	Dekaliter	dal.
	Liter	l.
	Deciliter	dl.
	Centiliter	cl.
Weight	Ton	t.
	Metric quintal	q.
	Kilogram	kg.
	Gram	g.
	Decigram	dg.
	Centigram	cg.
	Milligram	mg.

The increasing use of the metric system in professional literature is a symptom of progress which requires a retrospect of several years for reliable observation. To present it in definite shape, a count has been made of the linear scales upon the illustrations published in "Engineering," the London weekly, during the years of your committee's existence. The following table gives the result:

Year.	Number of metric linear scales.	Number of non-metric linear scales.	Total number of linear scales.	Per cent. of metric scales in the total number.
1875	38	169	207	.18
1876	74	320	394	.18
1877	37	214	251	.15
1878	79	262	341	.23
1879	99	335	434	.23
1880	67	210	277	.24

The last column imperfectly shows the change that is slowly and surely taking place in the relative use of the metric and non-metric measures; how great the relative use is, it does not show; for the drawings that are made and figured by the metric system are generally published in "Engineering" with the addition of a linear scale of feet, though frequently they do not have any metric linear scale; but it is very rarely that a drawing in feet has a metric scale added upon publication.

A more marked illustration may be found in the transactions of the American Society of Civil Engineers. During 1880, besides the discussion of interoceanic canal projects, considerable of which was in metric measures, there were published three other papers that were either written in the metric system or with duplicate metric and old values; the society also distributed copies of a report upon the Sao Francisco River in Brazil, written chiefly in meters with occasional equivalents in parenthesis. Previously to 1880 the use of the metric system in that society's transactions consisted of a few metric scales on the illustrations, and some references in the text where the metric were evidently subordinate to the old measures.

CURRENT DISCUSSION.

The discussion of the metric question continues brisk. Col. Sedgwick's decimal system, mentioned above as opposed to the metric, was presented to the American Society of Civil Engineers, May 19, 1880. Col. W. Milnor Roberts, past president of that society, now in the employ of the Brazilian government, writes in "Journal of the Franklin Institute," for November, 1880 (pages 24, 25), a letter in which he speaks of the recent introduction of the metric system into Brazil, and of its probable ultimate adoption by the United States. During the last year the American Metrological Society has published, in two volumes, its proceedings from December, 1873, to December, 1879. The Ohio Auxiliary Society of the International Institute has also published its proceedings from December, 1879, through July, 1880.

The Engineers' Society of Western Pennsylvania took up the subject at several meetings. Mr. William Kent opened the discussion with an instructive paper, March 16, 1880, which he seemed to think himself might be criticised as "straddling" the question; he humorously compared himself to Ensign Stebbins, who was "in favor of the law, but agin its enforcement." Lieut. F. A. Mahan read a paper May 18, 1880, explaining simply what the system is, and forcibly presenting the leading arguments in favor of its adoption. Mr. James Park is quoted as saying "that he didn't know anything about it, and didn't want to know anything about it." A brief notice of the debate is given in "Engineering News" of May 22, 1880. The written papers were printed in the

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society's transactions. Lieut. Mahan's paper was also published in the "American Manufacturer" of June 11 and 18, 1880.

Mr. Greeley's remarks at the May meeting of the Civil Engineers' Club of the Northwest constitute a simple and brief presentation of the argument in favor of his resolution already quoted; they were published in the "American Engineer" for June, 1880, and contained the following reply to an objection:

"Mr. Coleman Sellers, whose opinion is entitled to respect, thinks the cost will be very great in machine shops and factories, and estimates it for a machine shop employing 150 men at something like $150,000. But in this he includes the entire change or removal of all patterns, taps, dies, thread cutters, and measuring apparatus of all sorts. Other gentlemen as competent to judge, and in charge of large works, think this wholly unnecessary, and believe that simple and convenient expressions will be found in metric terms for values which we now express in inches and fractions down to thirty-seconds without any change in the dimensions of the thing itself. It will not be necessary to change the width of a railroad track. The value of 4 feet 8½ inches is 1 435 m. The metric expression takes fewer figures and symbols. It will be known then, as now, as the 'common gauge.' No doubt the tendency would be towards dimensions expressed in even figures, but the change would be gradual, and attended with little cost."

At the first annual meeting of the American Society of Mechanical Engineers, Mr. Coleman Sellers read a paper entitled "The Metric System: Is it wise to introduce it into our Machine Shops?" It was published in the "Journal of the Franklin Institute," November, 1880; in the "Railroad Gazette," Nov. 26, 1880; in "Engineering News," Nov. 20 and 27; in the "American Architect and Building News" of same dates; imperfectly in the "Iron Age" of Nov. 11; and very likely in other places to your committee unknown. The interesting character of the paper, as well as its author's reputation entitles it to this wide circulation, which enables all who are interested to read and judge it for themselves. That Mr. Sellers has written this paper four years after the adoption of the Franklin Institute Report of 1876, is an encouraging item of progress, and excites curiosity as to what he will say in 1884. It may be remembered that in obedience to your vote of Nov. 17, 1875, your committee sent to the Franklin Institute, among other bodies, a letter saying: "That the numerous and very great obstacles in the way of this reform can be surmounted by conducting it in a deliberate and judicious way is proved by the history of the recent adoption of the metric system in Germany;" which it then proceeded to sketch very briefly, closing with a snggestion that that example had better be followed in this country. As it happened, France was not named in the letter. The reply received from the Franklin Institute in November, 1876, was accompanied by a copy of the report of a majority of their committee, to whom the letter had been referred, bearing, as the names of its signers, first, Coleman Sellers, second, W. P. Tatham, Chairman. That report was chiefly made up of fragments of French history, with brief allusions to irreligion, paternal government, the revolutionary calendar, etc. Most of its facts are to be found in John Quincy Adams' report, made in 1821, and it contained but little to show that its authors had learned of anything that occurred subsequently to that date, and certainly not the remotest allusion to Germany from beginning to end. In 1880, Mr. Sellers takes the trouble to say, with his compliments, that it was Mr. Tatham that wrote that report, and a prominent topic of his paper is the adoption of the metric system in the machine shops of Germany, upon which he dilates as fully as if the subject had the charm of novelty. He brings out in a strong light the fact that the complete adoption of the metric system means changing old standard sizes, and states what standard sizes are used in Germany for scales of drawings, for bar iron, for shafting, and for twist drills. His opinion is, that in point of convenience, these contrast unfavorably with the corresponding series now in use in the United States, though in another part of his paper he makes the general remark that some happy coincidences are found in the use of the metric system, as well as of the old weights

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and measures. What he dwells upon most, introduces several times, and gives comparative tables for, is the system of screw threads for bolts and nuts. The Whitworth system, based on the English inch, being in use in Germany, it was found impracticable to change it; so they adhere to it still, but have slightly altered the nomenclature, which Mr. Sellers condemns in these words:

"Having given up the inch, the Germans formulate their threads per diameter. For the names of the bolts they must either retain their English names, and call a 25.4 mm. bolt one inch, or they must call it what it is, 25.4 mm.; but some call it 25 mm. and make it .4 mm. larger. This inch bolt has 8 threads per inch, and as the diameter, too, is 1 inch, it can be said to have 8 threads per diameter. A $1\frac{1}{8}$ inch bolt measures 28.5 mm.; it may be called 29 mm. size; it must be cut out of 29 mm. iron, the nearest merchant size, with a loss of $\frac{4}{10}$ of a millimeter. This loss does not seem much, but the dies which have to cut it off tell the story very soon. The Whitworth scale gives the same pitch to $1\frac{1}{8}$ and $1\frac{1}{4}$ screws, viz., 7 per inch. The exclusive metric shops call the one $7\frac{1}{8}$ threads per diamter, and the other $8\frac{2}{4}$, and yet they are practically the same, and must be cut with same combination of change wheels on the lathe. Here is a precious example of what comes from trying to harmonize two systems under one nomenclature. The screw system in general use is so good, it has been so long in use, its disturbance would shock so many interests, that it is unwise to give it up," etc.

That it would be feasible to give it up if there were good reasons for doing so, appears from a paper,* read by Mr. Coleman Sellers in 1874, in which the following passage occurs:

"I have said business men count the cost before making changes in matters of habit or use; but when they can be shown that they will be gainers by the change, they give in to it heartily. This same example of screw threads will serve as an illustration. Mr. Whitworth's system of screw threads was already introduced in all the principal workshops of Europe. and in many in this country. But a better system was presented to the Franklin Institute, a system based on such simple laws, that, given the formula with no existing original to copy, any careful workman can originate a given thread that will match those in use. After an exhaustive debate on the subject of its introduction by the various departments of our government, and a careful consideration on the part of our mechanical associations, it came to be adopted as the United States standard. It was adopted at considerable expense, because it was believed to be an improvement on existing practice. We have still to keep up our old taps and dies for repair work; but no mechanic has deemed the expenditure involved in the change other than judicious."

It was Mr. William Sellers who presented to the Franklin Institute this "better system." He was present by invitation at the meeting of the master car builders, in New York City, in December, 1879, when the subject of screw threads was considered, and it appeared that frequently bolts and nuts purporting to be of the Sellers standard were not interchangeable. Mr. Wm. Sellers said, among other things: "It seems to me that the trouble does not lie with the system of screw threads; no difficulty seems to exist there. The difficulty is the original one of what is an inch," etc. This is quoted from a tolerably full report in the "Railroad Gazette" of Jan. 2, 1880. For information on this subject, published during the past year, reference may also be made to a long editorial article in the "Railroad Gazette" of Jan. 9, 1880, and to the discussion in the meeting of the American Society of Mechanical Engineers, Nov. 5, 1880, reported in the "Iron Age" of Nov. 11, and to brief letters in "Engineering" of July 16 and 23.

One hundred and fourteen shipyard laborers from the Clyde recently arrived at Montreal on their way to Wynlock shipyard, at Detroit—all, the *American Manufacturer* says, under contract.

*The Metric System in our Workshops: Will its Value in Practice be an Equivalent for the Cost of Introduction? Read at the Chicago meeting of the American Railway Master Mechanics' Association, May, 1874, and published in the Journal of the Franklin Institute, June, 1874, and in the Railroad Gazette, Sept. 5, 1874.

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SUGGESTIONS FOR PREVENTING LONDON SMOKE AND MAKING IT COMMERCIALLY AVAILABLE.

By W. D. SCOTT-MONCRIEFF, C. E., F. R. S. S. A.

From the "Journal of the Society of Arts."

It is sometimes difficult to account for sudden movements of popular opinion. When once they begin, an element of momentum seems to take the place of the previous inertia, and the new form of social force appears frequently to be directly proportionate to the one which preceded it. We are now in the midst of one of these movements of opinion that is not difficult to account for. The interest which at present attaches to the question of how best to obtain the blessings of an uncontaminated atmosphere, has arisen out of a state of things with regard to smoke and fog, that is recognized as dangerous to the whole community. The work of relating the means to the end has commenced in earnest, and there is every likelihood that, before long, the public will be put in possession of information as to how the problem is most likely to be solved.

Some apology is, perhaps, necessary on my part to those who are at present exerting themselves as specialists in this field of inquiry, for not having laid my proposals before them to the exclusion of other channels. I am sure, however, that if any one of those gentlemen were in my place, they would have thought twice before rejecting so favorable an opportunity as the one which has been presented to me. The Society of Arts has already identified itself with this important subject. I trust that further facts and information may be brought to light by this additional discussion, and that they may prove useful to the committees whose praiseworthy efforts are, at present, being exerted for the public good.

The present position of the question renders it far from easy to know how best to deal with it before a scientific audience, who are well informed. Materials which were important contributions a few months ago, have already been assimilated, and no longer lend themselves to the further elucidation of the subject. I trust, therefore, I may be permitted to confine myself to the special scheme which I propose, and I need not say with what pleasure it is that I do so, when I tell you that, although it has occupied my thoughts for years, this is the first occasion upon which I have addressed an audience on the subject.

I wish, first of all, to attempt to make clear to you in a few words what is the present aspect of the question, as regards the methods and apparatus employed.

The classification of the methods may be arranged as follows:

1. Burning bituminous coal at a single operation, by exposing it to the heat of the fuel previously ignited. It is unnecessary to say that this method embraces nearly the whole of the domestic consumption of Great Britain, aad a great part of the commercial consumption as well.

2. Separating the gas from a cheap quality of coal, heating it in an apparatus known as a regenerator, and using it without the solid residue.

3. Separating the gas from the coal at a comparatively low temperature, adding the partly coked residue of a previous charge to the fuel in the furnace, and passing the gas through the burning mass.

4. Using coke as a basis, and passing gas through the fuel as a means of supporting its combustion, both coke and gas having been obtained from a gas company.

5. Using fuel from which a certain proportion of gas has been extracted, which is the special subject of the present paper.

As regards the apparatus, it naturally follows the classification of methods or systems, and would far exceed the compass of this paper to describe in any detail. It will be well, however, for me to

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say something of the more familiar appliances which are in every-day use, and to remind you of certain fundamental principles that are common to the whole of them. As you are all well aware, the combustion of bituminous coal depends upon the combination of certain gases, and of carbon and ogygen at a high temperature. It is also familiar to you all, that the oxygen necessary for this combustion is obtained from the atmosphere we live in. One necessary feature of the process is the creation of a draught, which is obtained, as you all are aware, by the action of a heated column of air in a shaft or chimney. But this invariable accompaniment of combustion is, in the nature of things, associated with a movement, not only of the air, but of the gaseous elements of the fuel, and it is almost inconceivable that the necessary quantities of oxygen can be obtained without this element of rapid movement. The question comes to be then, whether or not the mean velocity of the air and gases necessary to supply the oxygen, is compatible with the time that must elapse in order to obtain the necessary chemical combinations at the point of sufficient temperatures, which is in the body of the fire itself.

Now in the case of freshly added bituminous fuel placed on the top of a burning mass, it is quite certain that the conditions of a draught are inconsistent with complete combustion; and this brings us to a consideration whether or not it is possible to consume bituminous coal perfectly at a single operation, and leads to doubt as to the possibility of using the first method successfully in any apparatus, however ingeniously it may be devised for the purpose. Certain proposed processes are sometimes so inconsistent with the operation of invariable natural laws, that a conclusion on the subject of their failure has the certainty of a complete induction. If an apparatus depended upon its success on the tendency of water to run up hill, as in the case of many of our London house drains, we should be safe to predict its failure. The matter, as regards the complete combustion of fuel at one operation, is not quite in this elementary category, but, to my mind, it is very near to being so.

I am sure many present will sympathize with me in the great difficulty of making clear to others matters that do not contain within themselves all the elements of a complete induction. The induction may be so far complete, as regards oneself, that the mind is forced to a definite conclusion, but the discrepancies may, nevertheless, be the very elements which go to form a popular belief in another direction. I do not know of any better way of illustrating my meaning than referring you to several well-known fields of invention which, at one time, seemed to be altogether open, but which have become gradually closed with the advance of scientific knowledge. For instance, in the early days of steam locomotion, there must have been many persons who thought it presumption on the part of certain engineers to oppose themselves to the principle of the atmospheric railway. It must have appeared to them that it was wrong to predict the failure of science in one direction whilst anticipating its triumphs in another. And yet, I have no doubt, that men did appreciate at that time what was practically a complete induction in their own minds, however difficult it may have been to convey their arguments conclusively to others. Now, I do not know of any problem, at first sight, which gives a greater promise of a simple solution than the burning of an ordinary piece of household coal. The elements of combustion not only seem available, but, up to a certain point, lend themselves readily to a partial solution of the difficulty. Nothing is more easy than to get a fire to burn in an ordinary grate, and nothing is more difficult than to get it to burn in such a way that no smoke shall escape up the chimney. To predict the failure of all appliances for all time coming to attain this object is, therefore, on the face of it, an apparently rash anticipation, and yet there is nothing in the scientific aspect of the problem that suggests any other conclusion to my mind. I am not so much inclined to this opinion because of arguments that present themselves readily as the result of experiments on a small scale, but more from those which may be gathered from the experience of persons engaged in the consumption of fuel on a large scale, where the opportunities for carrying out complete combustion are exceptionally favorable.

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Taking the iron trade as a typical example, I may say that all experience in the direction of cleanliness and economy is tending rapidly towards a total abandonment of the attempt to burn bituminous coal at one operation. The appliance which perhaps presents the greatest exception to this rule is the blast furnace. The vast scale upon which the consumption of fuel is carried on in this apparatus, would of itself place it in an exceptional position as affording peculiar facilities for obtaining an intense and constant temperature. Even here, however, the operation is becoming, to a great extent, divided, and the utilization of the waste gases for heating the air stoves is of itself a proof that, even with all its peculiar advantages, the hot blast is unable to carry out complete combustion at one operation.

Here is an illustration of a blast furnace of a not very improved or modern type, but which is sufficient to show the immense advantage the apparatus has over anything that one can conceive of, in our present state of knowledge, in respect of a domestic appliance. The temperature is not only intense enough to melt iron, but it is maintained from one month's end to another with the skill and assiduity of trained workmen. The air is not only introduced in immense volumes by means of powerful blowing-engines, but is heated to a high temperature before it reaches the fuel. The artist has, I think, somewhat exaggerated the volumes of smoke escaping from the mouth of the furnace, but its presence at least shows he was conscious of its existence. Now, as a matter of economy, these waste gases are utilized in the modern practice of iron smelting, but if they exist at all under conditions so favorable to complete combustion, what shall we say of appliances that burn a few pounds of coal at a time under the charge of an overworked housemaid? I am not speaking now of perfect combustion, but only of that fair amount which is consistent with a smokeless chimney.

As regards other departments of the iron industry, the attempt to consume bituminous coal at a single operation is being altogether abandoned. The labors of Dr. Siemens, as embodied in his regenerative furnace, have gone far to bring about a change in the direction of scientific principles, and Mr. Price's furnaces, as now used at Woolwich Arsenal, are also an illustration of improvement that has taken place in the same direction. I shall have occasion to speak of these appliances presently. Now, without saying that arguments drawn from such channels are altogether conclusive, I must say, that along with other considerations, they go far towards the formation of an opinion that in cases where the scale of the consumption is smaller, success will be still more impossible of attainment. As regards the scale of appliances that come under the head of domestic apparatus, I believe that the problem of consuming ordinary bituminous coal at one operation will ultimately be abandoned altogether, but it is beyond all likelihood that it will ever be satisfactorily solved. A few years ago this opinion would have been looked upon as unreasonable. I have long been convinced that it is a sound one, and this belief is supported, not only by several eminent authorities, among whom I may number Dr. Siemens, but also by the whole tendency of the practical improvements which have been carried out in our great national industries. I believe it is capable of a theoretical proof; but even if this were wanting, I think I am justified in pointing to the present condition of our large towns as a demonstration of the failure of existing appliances. When the vast amount of invention which has been expended upon the problem of the complete combustion of bituminous coal at one operation is taken into account, and when it is considered that not one appliance has ever been altogether successful, I think there is a strong *prima facie* case made out against the practicability of the proposal. If I may be allowed to put the argument as near as possible in the form of a syllogism, with regard to domestic hearths, I might say all bituminous coal requires a high temperature steadily maintained for its complete combustion. Domestic fires are incapable of producing a high temperature steadily maintained, therefore domestic fires are unfit for the complete combustion of bituminous coal. To hold an opposite opinion with regard to the element of temperature is inconsistent with the facts, and to insist on the high temperature being continually maintained is to deprive every citizen of

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his right to allow his fire to go down when the heat he obtains from it has become excessive. I might quote many authorities in support of these opinions. Even in the case of steam boilers, where skilled labor is available, and where a high temperature, evenly maintained, is an important point, Dr. Angus Smith shows clearly that it is heat that is required for the complete combustion of the fuel, and that the supply of air in sufficient quantities is comparatively easy. I will suppose the case of an absolutely perfect domestic appliance for the combustion of bituminous coal, and I will ask the inventor of it where the heat has to come from that is essential to the process, when the fire has been allowed to go almost out, and the housemaid adds fresh fuel.

So far, I have tried to put the matter before you as regards temperature, but a moment's consideration of the actual process of combustion will, I think, make it equally impossible to escape from the conclusion to which I have come, even as regards the supply of air itself. Burning coals depend for their incandescence upon the passage of air among their exposed surfaces. In an open brazier, it may pass in from all sides, and underneath as well. So far this is a most favorable condition, but as it passes through the burning mass the oxygen is consumed, and it is impossible to insure that the air does not reach some parts of the fuel in an exhausted state. I have here a simple illustration of my meaning. This common paraffine lamp is so arranged that a current of air passes in close contact with the flame from the wick, and the oxygen is consumed in its passage. I will now suppose that this piece of bituminous coal, which I place over the top of the funnel, holds an analogous place to that which it might assume in the most ingeniously constructed stove imaginable, that is to say, some point at which the air, which has already passed through the fire, reaches it exhausted of its oxygen. The temperature of the lamp flame is sufficient to produce an escape of gas, and upon passing my hand over the funnel this is proved by the pungent smell of the gaseous products. Now you will find, that although the gas is escaping, the conditions are altogether inconsistent with combustion of any kind whatever. Upon striking a match, and bringing it near the top of the funnel, you will see that it is instantly extinguished. I now take a piece of smokeless fuel, and place it over the funnel, instead of the piece of coal. It goes without saying that although there is no more chance of combustion in the one case than there is in the other, still no smoke escapes, and, as far as the atmosphere is concerned, no harm is done.

I might multiply arguments indefinitely; but as time is of importance, I must ask even the unbelieving to accept my conclusions in the meantime, and simply point out that if they are right, the idea of adapting domestic hearths to the complete combustion of ordinary bituminous coal may be abandoned at once and forever. If smoke were like certain gases that burst into flame at a low temperature when they escape into the air, there might be some chance of obtaining a satisfactory result. But the fact that it does not ignite, even in contact with a red hot piece of iron, shows how temperature, beyond the capacities of an ordinary hearth, is essential to its perfect consumption. I have here a list of the gases contained in ordinary coal:

	Manchester gas.	Gas as supplied to Houses of Parliament.
Hydrogen	52.71	41.71
Marsh gas	31.03	41.88
Carbon monoxide	4.47	4.98
Olefines	11.19	8.72
Nitrogen	—	2.71
Carbon dioxide	0.58	—
	100.	100.

Now, some of these gases combine with oxygen much more slowly than others, so that some of them, in the case of an apparatus depending upon a draught (and I know of none in the nature of a domestic appliance that does not depend upon a draught), would be half way up the chimney before the combination was complete.

If these conclusions are right, an immense amount of ground is cleared as regards the solution of the problem, because the knowledge of what will be successful is, in nine cases out of ten, arrived at by discovering what cannot be successful in the nature of things. The conclusion means in other words, either

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that the use of ordinary bituminous coal must be abandoned altogether, or that some apparatus must be devised for domestic purposes, similar, on a small scale, to those which have been introduced in our great industries, more especially those in the iron trade, to which I have already referred. This brings us to speak of the second and third methods, and I shall do so in as few words as possible. I do not see how these can possibly be carried out, for the simple reason that on the large scale skilled labor and the means of maintaining a constant high temperature are essential features of complete combustion, and neither can possibly be present with any certainty in the case of domestic fires. Dr. Siemens has hit upon an ingenious plan, by which he makes use of the operations of gas companies to separate the operation of combustion, it may be, miles away from the point of domestic use. This is the fourth method I referred to. By burning coke with gas flames burning through it, he avoids the difficulties of separation as regards the consumer, and carries out a scientific system of combustion at the same time. I propose, however, instead of this, to use a modified condition of bituminous coal, and I will try to show the advantages of doing so. It might be presumption on my part to say that I am the discoverer of this sort of fuel, but I may say that, so far as I know, I am the first to bring it into public notice.

First, I may say that, with regard to anthracite coal, if the principle of smokeless fuel is once recognized and enforced the stone coal will fight its way, and be of great service, not only as a heating agent, but as a wholesome source of competition as well. It is as a means of saving our smoke and improving our light that I propose the fifth method, and I shall go on to describe it.

About ten years ago I made a series of experiments upon the separation of the process of combustion which led me to think very highly of the class of fuel to which I refer. I placed a small D retort in a common Cornish steam boiler, and by lowering the position of the fire bars, arranged an apparatus for the distillation of gas from the fuel in ordinary use, and after some time had elapsed, I discharged the gaseous contents of the retort into the furnace. In this way I secured practically complete combustion by a separation of the fuel into its constituent parts of solid carbon and hydro-carbon products. The semi-coke that resulted from this short distillation was practically smokeless, and I have since discovered that by treating it with water when hot, as in the case of coke, renders it still more smokeless. So far as I am aware, it is the most perfect fuel imaginable, as it has all the cheerfulness of ordinary coal, with none of the disadvantages arising from the creation of smoke.

I must now ask you to turn your attention to the present condition of London as regards its fuel, and to make an effort to realize how matters actually stand. Leaving out of question the coke which is consumed by the public, I want you to realize the fact that there are about four million tons of coal consumed in London every year. You may conceive of this, more readily, as a solid cube, with a base of about 200 yards, built square upon all sides, to the height of the cross on St. Paul's Cathedral. This is what is burned for the purpose of obtaining heat, in addition to the surplus coke sold by the gas companies. Bearing this in mind, I must now ask you to try to realize another quantity, viz., about 2,000,000 tons—used for the purpose of obtaining light. This would be represented by a cube about 140 yards at the base, built up to a height of 430 feet. All this vast quantity is passed through retorts, and, after a large amount of bad gas has been extracted from it, it is converted into cinders called coke. Now, it has entirely escaped observation that the gigantic appliances necessary for treating the one heap of coals on a long extraction, with bad results, is capable of extracting a small quantity from both heaps of coals on a short extraction, with good results both as regards gas and fuel. The fuel would be similar to that which resulted from the experiments I have referred to, the illuminating power of London gas would be approximately doubled, and the aniline dyes and ammonia, and other products of the process of distillation, must be doubled as well.

To those who may be ready to exclaim against the vast capital which will be required to carry out this operation, I will

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now show you how it is that no additional plant is necessary in order to obtain this result. We will begin by a familiar illustration. Supposing one of the smaller gas companies were to begin to-morrow to advertise and sell coal from which only 3,000 cubic feet of gas had been extracted per ton. The fuel must be cheap to the consumer at 23*s* per ton, and thus, to start with, the company would recoup its outlay for coal, which we will suppose cost them on an average about 16*s*. per ton. But, in order to keep up its normal production of gas, so soon as a retort was discharged, it would simply need to be charged again. In this manner gas would be coming away from the retort all day long, just as formerly, with a slight loss of time to be allowed for the additional frequency of the charging. As, however, the gas under the proposed arrangement comes off much more rapidly than under the existing system, the supply at the end of the 24 hours would be in excess of that which is obtained from the long extraction, and in this way less and not more plant would be necessary to give the same quantity in a given time. But instead of bad 12-candle gas, they would have 20 or 24-candle gas to dispose of, with double the quantity of bye-products to the good in addition. What applies to the case of one small company would of course apply equally to the whole combined.

I have already trespassed on your time at considerable length, but as there are no doubt many here present who prefer an ounce of practice to a hundred weight of theory, I think it well to tell you that my scheme has already been carried out at Woolwich Arsenal when all other methods had failed to supply the establishment with sufficient light. When I say my scheme, I say so with an important limitation in this particular case, because when I went to explain the proposal to Mr. Wallace, who is one of the most scientific gas managers in the kingdom, I found he had already been in the habit of adopting it. Curiously enough, however, he had never generalized from the facts, and until I pointed out the wide applications of which it was capable, had not thought of it as a means of utilizing the smoke of our great cities. During the long winter evenings, the available plant at the Arsenal frequently falls short of the demands that are made upon it. Under ordinary conditions, the supply of 16-candle gas is just sufficient for the purpose of supplying light, and if we take the quantity of this to be, say 100 cubic feet per unit of time, then if 20-candle gas were substituted, the quantity of light would be increased proportionately, that is to say from 100 to 125, in terms of a photometric measurement. Now, not only is this result obtained, as regards the quality of the gas, by simply removing one charge of coals at the end of four hours and substituting a fresh one, but larger quantities of the better gas are obtained, and that for two reasons. First of all, the gas comes off in greater quantities per unit of time on an average short extraction than on an average long one; and the fuel used for heating the retorts, being greatly superior to ordinary coke, assists the operation still further. In this way, then, the superiority of the short extraction is proved in all directions. I have here a few specimens of the fuel. No. 1 represents an extraction of 3,000 cubic feet per ton; and if it were used in London, this city would be rendered practically smokeless. I must explain, however, that an experimental retort does not give a fair specimen of the fuel. Measurement by the meter is the only method of guessing at the amount of extraction; but this is by no means a satisfactory test of the equable character of the distillation. That is to say, that the 1½ cubic feet of gas which may come away from 1 lb. of coal in an experimental retort, although a satisfactory test of the extraction being at the rate of about 3,000 cubic per ton, may, nevertheless, have come to a great extent from the outer surface of the sample, leaving the interior both bituminous and smoky. In an ordinary extraction on the large scale, the fuel may be taken as smokeless and in every way suitable for domestic consumption.

Perhaps, the most pleasant way to conclude this paper would be to draw a picture of the present state of London—overcast, filthy, given to fogs, grievous to breathe in—with the London of the future, clear as the tops of the Surrey hills, if the fuel I have been describing were in universal use. I must ask you instead, however, to follow me through a

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few figures which explain the financial bearing of my scheme upon the community generally.

First, then, as regards capital expenditure, I propose to take advantage of the existing plant of the gas companies. I find they are amply sufficient for the purpose.

Instead of taking 10,000 cubic feet of gas per ton from the coal, I propose to take 3,333 cubic feet, and to pass three times the quantity through the retorts, or in any other proportion that may be found most convenient. The result of doing so is startling.

The companies will have double the quantity of by-products they have at present in the shape of tar and ammoniacal liquids; the community will have 24-candle gas instead of 16-candle gas; the fuel resulting from the process will light readily, and it will make a cheerful fire that gives out 20 per cent. more heat than common coal; London would become a smokeless city.

In dealing with the figures, I shall take them roughly, but in such a way that by including a few outlying corporations they could be made absolutely correct.

I take the total annual consumption of coal in London to be 6,000,000 tons. Of this I take 2,000,000 tons to be the annual consumption of the gas companies. The total quantity of fuel used for general purposes I take to be 4,000,000 tons of coal and 1,000,000 of coke sold by the gas companies.

We shall now see what would be the result if we treat the whole of the 6,000,000 tons in the retorts on an extraction of less than three hours, instead of the six hours at present prevailing.

The total quantity of 16-candle gas consumed in London may be taken at 20,000,000,000 cubic feet. This would be at the rate of 3,333 cubic feet per ton upon 6,000,000 tons, the total quantity of coal consumed in London. The residual smokeless fuel would amount to 5,100,000 tons. Of this 1,000,000 tons would be required for the extraction of the gas, leaving 4,100,000 available for the general uses of the community. This has to be compared with the 4,000,000 tons of coal and the 1,000,000 tons of coke already referred to as consumed at present. Now, the smokeless fuel which results from an extraction of 3,333 cubic feet of gas per ton has a heating capacity fully 20 per cent. greater than common coal, and 10 per cent. greater than coke. This gives us the exact equivalents of the 5,000,000 tons of fuel at present in use.

So far the account, as regards the fuel available for the community, balances. We may now deal with the difference in value between 16 and 24-candle gas. As the value of the gas varies directly as its illuminating power, the calculation is very simple. If we take the average price of 16-candle gas to be 3*s.* 6*d.* per thousand cubic feet, we shall find the total value of the 20,000,000,000 consumed in London to be £3,500,000, but as we have by my scheme the same quantity of 24-candle gas, the value will be increased to £5,250,000; here then we have an annual sum of £1,750,000 to place to the credit of the system.

Turning now to the by-products: seeing the gas companies, by the new arrangements, would subject three times the quantity of coal to the heat of their retorts during the period when the tar and ammoniacal liquors pass off most rapidly, I do not think I am wrong in estimating the yield at double its present amount. Taking this upon the tar and ammonia to yield 3*s.* 9*d.* per ton of coal, we find the total value of these by-products to be, at present, on the supposed consumption by the gas companies of 2,000,000 tons of coal per annum, £375,000. This being doubled under my scheme, an additional sum of £375,000 must be placed to its credit.

But the basis upon which we have hitherto been arguing is that the gas companies under the proposed scheme are getting their coal for nothing. We have been supposing that the community become the purchasers of 6,000,000 tons of coal and hand it to the gas companies. At present London only pays for its general consumption on 4,000,000 tons of coal and 1,000,000 of coke. Let us now suppose that the companies pay the same sum annually that they do at present for their coals; if so, they would pay upon 2,000,000 tons, or an annual amount of £1,600,000, if their coals cost 16*s.* per ton. From this falls to be deducted the money they at present draw from their sales of coke, which, when taken at 6*s.*

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per ton of coal carbonized under the existing system, still leaves a sum of £1,000,000, which they could afford to pay per annum for the use of the 6,000,000 tons of fuel as proposed in my scheme. We will now take the total payments of the community for their coal to be upon 6,000,000 tons, for which we will further suppose they pay at the rate of 16*s.* per ton first cost. This would amount to £4,800,000 per annum. From this has to be deducted the £1,000,000 contributed by the gas companies for the use of the fuel, also the £1,750,000 charged on the difference between the 16 and 24-candle gas already referred to, also the sum of £375,000 of additional income from the by products. This would leave a net sum paid by the community for its fuel under my scheme of £1,675,000. Under the present system they have to pay, say 16*s.* per ton on 4,000,000 tons of coal, and say 12*s.* per ton on 1,000,000 tons of coke. This makes in all the sum of £3,800,000 per annum. Here then we have a balance in favor of my scheme of £2,125,000 annually. This may be taken as the yearly value of London smoke, which I propose to convert into useful products by the plant at present in use.

I have only, in conclusion, to say one or two words about the efficiency of the scheme as regards the fuel. It lights easily, it gives off no smoke, it makes a cheerful fire, it gives out more heat than either coal or coke, it will be cheaper per heat unit than the coal at present in use, London would become a smokeless city, and all that would fall to be deducted from the sum of £2,125,000 per annum would be confined to a few items, such as the cost of additional workmen employed in charging the retorts, interest upon additional capital required for transit appliances, and the terms to be made with the gas companies for carrying out the scheme.

I have much pleasure in acknowledging the help I have received from Mr. Wallace, the gas manager at Woolwich Arsenal, and the valuable information obtained from Mr. Field's tabulated accounts of the London gas companies. So far as I am aware, my contributions to the *Builder* and elsewhere are the only writing on the subject of my proposal that has ever been made public. I should say, in conclusion, that I have no pecuniary interest whatever in the scheme I propose.

ROMAN BUILDING IN ENGLAND AND IN ITALY.

From "The Builder."

An interesting description of the masonry of the portion of Roman wall lately discovered in the excavation for the Fenchurch Street Railway Station has been sent to the daily papers by the engineer of the Great Eastern Railway. The top of the portion discovered was about 9 ft. below the surface, and the bottom 9 ft. lower, giving a total of 18 ft., which very fairly corresponds to what we have before had occasion to mention as a rough scale for the accumulation of *débris* on town sites, of about 1 ft. per hundred years. There are, however, several particulars of an unusually suggestive nature with regard to this wall. We need only slightly refer to its ponderous strength—9 ft. in thickness at its foundations—a strength which, before the invention of gunpowder, was enough to guarantee a long resistance to even a pertinacious attack.

But it was not on mass alone that the Roman builder depended for security. When we consider the details of the present portion of his structure, we shall see how much thought has been given to the production of stable and durable work. Of the character of the cement used we shall have a word or two to say, only now remarking that after a lapse of more than 1500 years the solidity of the work is such as to render its demolition —even when attempted course by course —a very serious affair. The courses of wall are, in the main, 6 in. courses of random rubble, in limestone and mortar. But the thickening of the wall, not being effected by batter, but by steps, involved the introduction of a material that would

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afford a more level surface than rubble for the offsets—if we rightly understand Mr. Langley's expression, "projecting three inches." This material is afforded by what the account calls tiles, but which are really the Roman bricks, frequently found in ancient work in this country, and made and used to this day in Italy. These bricks are 17 in. long, 12 in. broad, and 1½ in. thick.

There can be no doubt that the Roman bricks were introduced in order to form plinths or level offsets, as three offsets on each side of the wall are thus finished. The value of the long flat form for bond is also to be remarked. The two upper layers, of three courses each, extended through the wall. The lowest layer, 18 in. above the foundation, was probably not far from the level of the soil. This course only extended 18 in. into the wall; the rubble being built on two layers of blocks of stone, each 9 in. deep, and about 2 ft. square. It will be very interesting to ascertain from what quarries the Romans brought the limestone to build the wall of London; and Mr. Langley will do good service to archæology, as well as to the kindred professions of the architect and of the engineer, if he will obtain an accurate analysis of the stone found, and aid in determining whence it was brought.

Under the stonework of the wall was a bed, composed of six layers of flint and clay, 2 ft., 6 in. deep. Whatever was the level of the soil, this, no doubt, must have been a sunk and buried foundation. There occurs a very remarkable parallel to the mode of preparing the foundation of the second city built on the site of Novum Ilium, in which cakes of clay were used as a sort of packing for the foundations. Between each course of flint in the London wall was a bed of clay about 1½ in. thick. This structure was carried down 3 ft. into a solid bed of gravel. It would seem as if the ancient builder was of opinion that, when protected from atmospheric effect, clay was reliable as a building material, and the existence of the wall confirms the truth of this opinion.

The Roman bricks are bright red, well burnt, and retain their form and sharp arrises. About the year 1844, during the construction of the railway from Gravesend to Rochester, specimens of Roman pottery were discovered, in which the bright red color, and smooth, sharp surface, were like those of Samian ware. But the simplicity in form of some of the articles was such as to render it highly improbable that they had been imported. Like the bricks, they must, we should conceive, have been British-made. One of the Gravesend vessels, more like the saucer of a garden-pot than anything else, but smooth and bright, had the word "graciscæ" on it in raised characters from an indented stamp. The Society of Antiquaries have not as yet explained this word. It seems to indicate the existence of some Roman earthenware manufactory in the valley of the Thames; and the red bricks in London wall seem to us to tell the same tale.

We now come to the question of the mortar. And here we would ask our readers to compare the perfect petrifaction of the lime used in the old Roman work in this country with the crumbling condition of the mortar in many of the ruins of 300 or 400 years later date. Who has not been struck with this in examining such a ruin as Kenilworth, or in making his way up the turret staircase of some long-deserted keep? If we compare the Roman mortar of the third or fourth century with the London mortar of to-day, what is the result? The architect shakes his head, but is unable to repress a smile at the question. "Yes," he says, "but look at the age of the one." Is that a satisfactory reply? We at once admit that a certain time is assignable during which well-prepared mortar gradually becomes more and more solid, more and more, to repeat the word purposely before used, petrified; but we do not think that, when a certain time has gone by, the process continues. Between a house of six weeks old and one of six years every one can perceive the difference. Go back to sixty years and you may, perhaps, say the same. From 60 to 600 we are not prepared to say what takes place. But as between, let us say 1,200 and 1,600 years, we do not think that at all events any solidifying process goes on. Things being alike—that is to say, the mortar being as well made by the castle builders of the twelfth or fourteenth century as

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by the wallers of the third or fourth century, we think that any difference in solidity could not be expected to be in favor of the latter.

We conclude, then, that the builders of the Roman wall of London made use of British materials, to which they applied the patient forethought and thorough integrity of execution that characterize Roman work. They dug the clay of the valley of the Thames, and instead of moulding it into thick blocks hard to bake, and next to impossible to bake thoroughly through, they moulded it into flat 1½ in. plates, on which the vitrifying process could have full effect, and which are almost, if not quite, as durable as fire-brick. As to brick, then, there is no doubt. But how about the mortar? As to that, also, we have ourselves no difficulty. The Romans used British lime, whether burnt from the chalk from Gravesend or from some other and harder stone it is for the chemist to tell us; but they made it into mortar in the Roman method. What is that? a reader may ask. We have, we think, before now, mentioned in these columns what it was; but, if so, it may well bear to be repeated. It was the diametric opposite of the present English method. There are many builders and persons conversant with public works who can remember the immense care which Mr. Brunel bestowed upon his specifications, and the elaborate system of inspection by which he effected the practical application of his rules. No one, as far as our experience goes, in modern times, so labored to secure the greatest excellence of work. In fact, it is well known that what Mr. Brunel called rubble would be called ashlar by some of his contemporaries, and that the rigidity with which his orders were carried out made it by 10 per cent. or 20 per cent. more costly to execute his designs than those of some of his brethren. Mortar, of course, exercised much of his care, and the mortar that he used was mixed hot from slacking the lime. If any remained to the next day, it was to be thrown away. Such was the specification; and although that was an extreme case, we apprehend that nine builders out of ten would say, if it erred at all, it erred on the right side.

In Italy an opposite view is taken, and an opposite method is adopted. The first practical preparation for building in that country is to dig a large oblong square pit, into which the lime is thrown when burnt, and covered with water. It is thought desirable to throw in at once all the lime that will be required for the building, and the longer it is before it is used the better it is considered to be. It forms a dense paste, which is taken out with a spade and mixed with sand or pozzuolana as required. It is usual to keep it moist, but we have never heard of or seen any thrown aside for any cause at all. The magnificient character of the work done with this mortar is well known. The Italians of many districts are born masons. Where we should call in the carpenter, and rig up a shore, a center, or a set of props, the Italian builder runs up a temporary wall. He saves the cost of wood, for he can use the stone over again; and his temporary work, if required, will last almost as long as his permanent work. In the cases, which are far from uncommon, of damage to building from earthquake, the wonderful celerity with which they are repaired is quite a phenomenon. Again, many of the Italian roofs are made of a species of mortar, a mixture of lime and clay, beaten for a week or ten days incessantly with clubs or mallets. The surface is quite watertight, a condition by no means to be obtained by English mortar. Again, for plasters of all kinds, down to the smooth surface which lends itself to the rapid brush of the frescoe painter, the excellence of the Italian lime, notwithstanding the wide geological range from which the limestone is taken, is something that is unattainable in England. It is all very well to say that the genius of the English school does not tend to work in fresco; there is something more than that. The English artist has not the opportunity of exercising himself by that most artistic use of his implements.

We recently saw a very remarkable illustration of the difference effected in the same material, and that, too, a cement, by the mode of treatment. We know an artist of rare patience and skill in the restoration of broken china. We know of a dragon vase, once fractured into twenty-five pieces, and of a china

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plate, shivered into nearly forty bits, that are now on their owner's shelves, without any visible mark of a crack. The cement that was used is that known as the "Mend-all cement"; but, of course, the skill goes for much more than the choice of material.

The artist in question, however, has long been careful to procure the smallest possible bottles of the cement; and that for the following reason: The material is prepared for use by dipping the bottle containing it into hot water. It then becomes fluid, and is easily applied to the edges to be joined, the fragments being themselves kept in hot water, and taken out and wiped before being cemented and put into place. If a large number of mends are made, and the whole affair gets out of shape—which it is very difficult in that case to avoid—the mended article is again put in very hot water, when it comes to pieces at once. Each piece has to be carefully wiped and re-cemented.

The objection to large bottles of cement is this—hitherto a perfectly empirical one:—After the cement has been liquefied and cooled a certain number of times, it becomes refractory. It no longer liquefies easily, if at all. It makes bad mends, or is altogether useless.

To this long-observed fact, a second observation has been added, within the last few days, which is highly significant. The bell of a "Queen's" reading lamp, which had a large piece broken out of it some years ago, was mended by the artist in question, and has been in nightly use ever since. After the fashion of mended things, this glass shade has outlived its more robust brothers. But the line of junction was visible, and the repairer thought that it would be an improvement to wash the bell, remove the old cement, and re-cement it. The bell, however, thought otherwise. To the surprise of the operator it laughed at the hottest water, and absolutely refused to allow the crack to re-open, or the cement in any way to soften or dissolve.

This phenomenon is worthy of reflection. It is impossible to disconnect it from the behavior of the cement in the bottle. The shade of a queen's lamp does not get so hot as to burn one's fingers, but it gets warm. The mended individual has thus been warmed and allowed to cool at least a thousand times. At what stage in the process the chemical change was complete it is impossible to tell. Very likely in twenty or thirty days. But slowly and gradually the cement has so parted with some element of solution as to vitrify, or, at all events, to unite itself with the glass in a union indissoluble by the agency of hot water, the original solvent of the preparation.

We cannot bake walls, unless it be by selecting very hot weather for their construction. On the other hand, we can avoid that soaking of the bricks, if rain happen to come on during the process of building, of which no notice is now usually taken. We know of one costly building, of which the color is permanently and entirely ruined by this neglect. Our object is to induce the Royal Institute of British Architects, the Institution of Civil Engineers, or others whom it may concern, to investigate this important fact of the behavior of lime or other cement. What is the effect of time on their cohesive force? Should time be allowed to elapse before the use, as is the case in Italy? Should it be combined with repeated rise and fall of temperature, as in the case of the Mend-all cement and of the lamp-glass that we have cited? Will an exposure of a certain duration to a steady heat have the same effect? And, if so, what heat, and for how long applied? These are questions of primary interest to the architect. Their solution may place a new material within his grasp. He may be enabled to rear those egg-shell domes which the imagination of Bulwer fashioned for the homes of the "Coming Race." We can never tell how far a new idea may carry us. We strongly suspect that the builders of the earliest bridge over the Tiber, or of the walls of Rome—certainly that the builders of the Roman wall of London—had a much clearer insight into the relation between the time spent in preparation and the permanent durability of work, than has any writer or lecturer on structures at the present day. We are not now speaking of those "Jerry builders" of whom a contemporary justly observed, *àpropos* of this very discovery of a Roman relic, that the Romans would have thrown them from the Tarpeian rock. We are speaking of thoughtful

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and experienced men. We are quite sure that Isambard Kingdom Brunel, were he now alive, would respond to our words by an elaborate series of experiments; and that if the result confirmed the practice of the Italian builder, he would then and there have re-drawn his specifications. We know not on whom now to place confidence for an equally earnest and practical desire to reply to such a question, but we trust that each and all of our friends who have the opportunity will do their best to aid in the formulation of the answer.

THE MANUFACTURE AND USES OF CAST STEEL.

From the "English Mechanic."*

The first question which the user of cast steel has to answer is, to decide which of the three great methods of making steel produces a material best adapted to his own wants. Sir Henry suggested to you, in his admirable lecture, that Bessemer steel would answer every purpose for which steel is used, with the possible exception of the steel required to make Canadian axes. There can be no doubt whatever that the Bessemer steel, of which Sir Henry gave you the first analysis, would have made an excellent Canadian axe had it contained the proper quantity of combined carbon. The only doubt I feel is whether it could be produced of sufficient soundness without so large a percentage of waste as not to raise the price beyond that at which crucible cast steel for Canadian axes is now sold. I must confess that my experience of Bessemer cast steel would incline me to say that it could not. In spite of the prejudice that exists among consumers of steel, such is the competition of the present day that I am sure that if steel could be produced of as good quality, and cheaper in price, by any other process than that of melting in crucibles, the present melting furnaces of Sheffield would rapidly melt away into old bricks and mortar. I venture to express the opinion that the reason that high-class Bessemer steel is not as good as high-class crucible cast steel is because the former cannot be made sufficiently sound without the admixture of silicon and manganese, both of which substances are injurious to cast steel for most purposes. I fear that the advantages supposed to be derived from the use of manganese in the manufacture of cast steel are, to a large extent, illusory. I have frequently conversed with consumers of steel who knew the trade before the introduction of spiegel iron into Sheffield, and it is remarkable how many of them expressed the opinion that the crucible cast steel now in use is not as good as it was when they were young.

To obtain sound ingots from high-class iron it is necessary to boil the steel for nearly half an hour after it has become fluid, and then to allow it to cool down to a certain temperature before it is poured into the mould. The process is called "killing" the steel, and it is an axiom amongst them that the higher the quality of the steel the more "killing" it takes. It is in this part of the process of crucible cast steel-melting that the virtue of the process consists; and the cost and quality of the cast steel produced depend in a large degree upon the skill brought to bear upon it. My theory is that the reason why high-class steel has to be so long boiled is to get rid of its occluded gas, which would otherwise produce bubbles or "honeycombs" in its attempts to escape. The addition of a portion of scrap steel much assists the "killing," as would naturally be the case if we suppose the scrap, which has been melted before, to have parted with its occluded gas in the first melting. That the presence of manganese or silicon helps largely to "kill" the steel, I account for on the theory that the carbonic acid unites with the manganese or silicon, and becomes a solid. So far, my theory appears to hold water pretty well; but when I come to the fact that low-quality cast steel—for example, steel melted from Bessemer rail scrap, which contains from 0.15 to 0.05 per cent. of phosphorus—does not require any "killing" at all, and may be poured into the mould as hot as the strength of

* Abstract of a lecture by Mr. Henry Seebohm.

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the crucible will allow, I am obliged to admit that I am not chemist enough to give you an explanation of the cause. The main point which I wish to impress upon you is that the much-maligned rule of thumb, which insists upon the superiority of crucible cast steel over Bessemer steel for certain purposes, may have a scientific basis, and must not be hastily set aside as prejudice.

Having decided by what process the steel is to be made, the next question that should come before the consumer of cast steel is the percentage of carbon which he wishes it to contain. When I first began business, the "temper" of steel, or the percentage of carbon which it contained, was concealed from the consumer. The following is a list of the most useful "tempers" of cast steel:

Razor Temper (1½ per cent. carbon).—This steel is so easily burnt by being overheated that it can only be placed in the hands of a very skillful workman. When properly treated, it will do twice the work of ordinary tool steel for turning chilled rolls, &c.

Saw File Temper (1⅜ per cent. carbon).—This steel requires careful treatment; and although it will stand more fire than the preceding temper, should not be heated above a cherry-red.

Tool Temper (1¼ per cent. carbon).—The most useful temper for turning tools, drills, and planing-machine tools in the hands of ordinary workmen. It is possible to weld cast steel of this temper, but not without care and skill.

Spindle Temper (1⅛ per cent. carbon).—A very useful temper for mill-picks, circular cutters, very large turning tools, taps, screwing dies, &c. This temper requires considerable care in welding.

Chisel Temper (1 per cent. carbon).—An extremely useful temper, combining, as it does, great toughness in the unhardened state with the capacity of hardening at a low heat. It may also be welded without much difficulty. It is consequently well adapted for tools, where the unhardened part is required to stand the blow of a hammer without snapping, but where a hard cutting edge is required, such as cold chisels, hot salts, &c.

Sett Temper (⅞ per cent. carbon).—This temper is adapted for tools where the chief punishment is on the unhardened part, such as cold setts, which have to stand the blows of a very heavy hammer.

Die Temper (¾ per cent. carbon).—The most suitable temper for tools where the surface only is required to be hard, and where the capacity to stand great pressure is of importance, such as stamping or pressing dies, boiler cups, &c. Both the last two tempers may be easily welded by a mechanic accustomed to weld cast steel.

Next to quality, by which is meant the percentage of phosphorus, sulphur, silicon, manganese, &c., the most important thing is temper, or percentage of carbon. For many purposes, indeed, temper is of more importance than quality. Nothing is more common than for steel to be rejected as bad in quality because it has been used for a purpose for which the temper was unsuitable.

When the steel has arrived in the user's hands, the first process which it undergoes is the forging it into the shape required. This process is really two processes. First, that of heating to make it malleable, and second, that of hammering it, while it is hot, into the required shape. The golden rule in forging is to heat the steel as little as possible before it is forged, and to hammer it as much as possible in the process of forging. It is impossible to lay down exact rules for each of the thousand-and-one tools in which steel is used. The treatment of each tool, in each process which it undergoes, is an art that can only be learnt by practice, and can no more be taught in a lecture than the arts of skating, riding, or swimming. The utmost that can be done is to lay down certain general rules, and, if possible, to attempt some scientific explanation of them, to elevate them above the despised position of rules of thumb. The worst fault that can be committed is to overheat the steel. When steel is overheated it becomes coarse grained. Its silky texture is lost. If the temperature be raised above a certain point, the steel becomes what is technically called "burnt," and the amount of hammering which it would require to restore its fine grain would reduce it to a size too small for the required tool, and the steel must be condemned as spoilt. Overheating in the fire is the primary cause of cracking

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in the water. The quality of steel may be so bad, *i. e.*, the percentage of phosphorus in it may be so high, that the amount of heat absolutely necessary to forge it at all into the shape required may cause it to crack in hardening. One of the principal reasons why a high-class quality steel is required for certain purposes is that it will suffer less injury by being heated to a greater degree, or by being heated and reheated a greater number of times than inferior qualities of steel. In heating steel the happy medium must be attained between heating it too much and too little, and between letting it lie too long "soaking" in the fire, and not "soaking" it through: Both the degree of temperature and the duration of the heat must be carefully watched. Some tools, such as circular cutters, files, &c., after they are forged into the shape required, must have teeth cut into them. Before this can be successfully accomplished, a preliminary process has to be gone through. The process of hammering or forging the steel into the shape required has hardened the steel to such an extent as to make the cutting of teeth into it impossible or difficult. It must consequently be annealed. This process, like the preceding one, is a double process. The steel must be reheated as carefully as before, and afterwards cooled as slowly as possible. Many tools are only required to be hardened on a small part of their surface, and it is important that the unhardened parts should possess the maximum amount of toughness, the minimum amount of brittleness, that can be attained. These tools must also be annealed after they are forged. The process of annealing, or slow cooling, leaves the steel coarse grained, gives it its maximum of ductility, and causes it, in fact, to approach the properties of lead.

We now come to the culminating point in our manufacture, where the invaluable property which distinguishes steel from wrought iron or cast metal is revealed, a process by which we suddenly change our steel from lead into glass—the process of hardening. In this, as in all other processes which steel has to undergo, we have to run the gauntlet of fire. We do so, however, at greater risk than heretofore. The forging of our tool is finished; it has taken the final shape to which we have destined it, and whatever injury we inflict upon it by overheating is irrevocable, and can no more be cured or mitigated by the hammer. We must, therefore, double and redouble our care, lest the temperature be raised above the point necessary to insure the required hardness. The part of the tool required to be hardened must be heated through, and heated evenly, but must on no account be overheated. Our tool must be finished at one blow—the blow caused by the sudden contraction of the steel produced by its sudden cooling in the water; and if this blow is not sufficient to give to the steel a fine grain and silky texture; if, after the blow is given, the fracture, were it broken in the hardened part, should show a coarse grain or dull color, instead of a fine grain or glossy luster, our tool is spoiled, and must be consigned to the limbo of "wasters." The special dangers to be avoided in hardening each kind of tool must be learnt by experience. Some tools will warp or "skeller," as we say in Yorkshire, if they are not plunged into the water in a certain way. Tools of one shape must cut the water like a knife, those of another shape must stab it like a dagger. Some tools must be hardened in a saturated solution of salt, the older the better, whilst others are best hardened under a stream of running water. Most tools have a tendency to watercrack if taken out of the water before they are absolutely cold. Where the edge of a tool only is hardened, care should be taken to move it up and down in the water, so as continually to change the water level, lest the tool should crack at the water level. Steel contracts in hardening, and contracts most when it is cooled most suddenly. If the hardened part join on to the unhardened part too suddenly, the steel at the junction will be in a dangerous state of tension which predisposes it to crack, and it is wise to lessen the amount of tension by distributing it over as great an area as possible. In some tools where the shape necessitates a great difference in the rapidity of cooling, it is wise to drill holes in the thicker parts where they will not interfere with the use of the tool, holes which are made neither for use nor ornament, but solely with the view of equalizing the rapidity of the

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cooling of the various parts, so as to distribute the area of tension, and thus lessen the risk of cracking in hardening.

Our difficulties are not quite over when the process of hardening has been successfully accomplished. Our steel was originally lead; it has now become glass. But we do not want glass: it is too brittle; we want whalebone. An unhardened knife would bend like wrought iron; a knife hardened only would break like cast metal. We want both qualities combined—the bending quality of the iron and the resisting quality of the metal. We want the elasticity of the whalebone. Our knife must spring like —like what?—like *steel*. To attain this our tool must pass through the final process—that of tempering.

If you heat a piece of hardened steel slightly, and allow it to cool again, it becomes tempered. It suddenly changes from glass to whalebone: and in the process of changing its nature, it fortunately changes its color, so that the workman can judge by the hue of the color the extent of the elasticity which it has acquired, and can give to each tool the particular degree of temper which is most adapted to its special purpose. The various colors through which tempered steel successively passes are as follows: Straw, gold, chocolate, purple, violet, and blue. Of course, in passing from one color to another, the steel passes through the intermediate colors. It really passes through an infinite series of colors, of which the six above mentioned are arbitrarily selected as convenient stages.

It must be borne in mind that the elasticity of tempered steel is acquired at the expense of its hardness. It is supposed that the maximum of hardness and elasticity combined is obtained by tempering down to a straw color. In tempering steel regard must be had to the quality most essential in the special tool to be tempered; for example; a turning tool is required to be very hard, and is generally taken hot enough out of the water to temper itself down to a degree so slight that no perceptible color is apparent, whilst a spring is required to be very elastic, and may be tempered down to a blue. If you ask me to give you a scientific explanation of the process of tempering steel, I must confess my absolute ignorance. I have no more idea why it is so than the man in the moon, and the utmost I could do would be to mystify you in talking unintelligibly about molecular rearrangement and crystalline transformations. Hardening in oil is another mode of treating steel, which appears to a certain extent to attain by one process the change from lead into whalebone without passing through the intermediate glass stage, and is of great value for certain tools.

There are many kinds of steel to which your attention should be called, but which can only obtain from me the briefest mention. A special steel for taps, called mild-centered cast steel, is made by converting a cogged ingot of very mild cast steel, so that the additional carbon only penetrates a short distance. These bars are afterwards hammered or rolled down to the size required, and have the advantage of possessing a hard surface without losing the toughness of the mild center. Another special steel, somewhat analogous to mild-centered cast steel, is produced by melting a hard steel on to a slab of iron, or very mild steel heated hot enough to weld with the molten steel, so that a bar may be produced, one half of which is iron and the other half steel, or three-fourths iron, and one-fourth steel, as may be required.

A third kind of special steel, which is used for turning tools for chilled rolls, magnets, and some other purposes, is made by adding a certain percentage of wolfram, or, as the metal is more generally called, tungsten, sometimes with and sometimes without carbon, sometimes to such an extent that it can be used without hardening in water. Special steel of this kind is the finest grained that can be produced, but it is so brittle that in the hands of any but exceptionally skilled workmen it is useless. The addition of chromium, instead of wolfram, has somewhat the same effect.

It is much to be regretted that no easy method of testing cast steel has been invented. The amount of breaking strain and the extent of the contraction of the area of the fracture are all very well for steel which is not hardened, and not required to be used in a hardened state, but for hardened and tempered steel it is practically useless. It is very difficult to harden and temper two pieces

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of steel to exactly the same degree. A single test is of comparatively small value, as a second rate quality of steel may stand very well the first time of hardening, but deteriorates much more rapidly every time it is re-hardened, than is the case with high-quality steel. Nor am I at all sure that the breaking strain is a fair test of the quality of steel. For many tools the capacity to withstand a high amount of breaking strain slowly applied is not so much required as its capacity to withstand a sudden shock. The appearance of the fracture is very illusory. The fineness of the grain and the silkiness of the gloss is very captivating to the eye, but it can be produced by hammering cold. The consumer of steel may be enraptured, if he be of a poetical turn of mind, by the superb fracture of a bar of steel, reminding him of a picture by Ruskin of the aguille structure of the Higher Alps; but, after all, this is only a dodge, depending upon the inclination of the axis of the revolving hammer to the plane of the anvil. The practical consumer of steel must descend from the heights of art and science, and take refuge in the commonplace of the rule of thumb, and buy the steel which his workmen tell him is full of "nature" and "body."

EXPERIMENTS ON THE STRENGTH AND STIFFNESS OF SMALL SPRUCE BEAMS.

By F. E. KIDDER.

From Proceedings of the American Academy of Arts and Sciences.

The object of the following experiments was to determine the Moduli of Elasticity and Rupture in small beams of white spruce (*Abies alba*); and such other information as might be derived from the data obtained.

The machine used for the purpose consists of two solid wooden frames, carefully leveled and placed forty inches apart. Upon the top of each frame is placed a movable plate of iron, which is carefully adjusted so that the two plates shall be directly opposite each other, and exactly forty inches apart between the faces. These plates form the supports for the beams.

The loads were applied by means of a scale pan suspended from a three-quarter inch bolt, which rested upon the center of the beam. By means of an iron strap suspended from a horizontal beam placed above the test piece, and resting on two screws, the bolt from which the load was suspended could be raised from or lowered upon the test piece as easily and gradually as could be desired.

The deflections of the beams were measured by means of a micrometer screw, reading to one ten-thousandth of an inch. As the bolt from which the load was suspended rested on the center of the beam, it was necessary to measure the deflections at a distance of one-inch from the center; but the deflections used in calculating the values of the Modulus of Elasticity were corrected so as to give the deflection at the center, supposing the curve assumed by the beam to be the arc of a circle; from which, in fact, it deviates but little under such small loads. In reading the micrometer, the principle of electrical contact was taken advantage of.

The greatest errors liable to occur in using the machine are as follows:

In measuring the deflections, one ten-thousandth of an inch. In the breaking load, possibly one pound; but in the small loads there could be no appreciable error. In measuring the dimensions of the test pieces, two thousandths of an inch.

The experiments were conducted with the utmost care, and every possible precaution was taken to prevent errors.

In arranging for the experiments, and while making them, the writer was greatly assisted by Mr. Holman of the Institute, to whom he extends his acknowledgements.

The pieces of wood experimented on were sawn from a spruce plank that had been cut in eastern Maine in the spring of 1880, and the following summer

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shipped to Boston, where it had lain in the open air until it was cut up in October. The pieces were carefully planed to an approximate size of one and a-half inches square and four feet long.

They were nearly all straight-grained and had but few defects, and in testing the beams they were placed so that the defects should have the least possible effect upon the strength of the beams. The exact dimensions of the test pieces are given in Table I:

TABLE I.

No. of Test Piece.	Clear Span. l.	Breadth. B.	Depth. D.	E.	E_1.	R.	Center breaking weight for beam 1″×1″×1′.
	ins.	ins.	ins.	lbs.	lbs.	lbs.	lbs.
1	40	1.475	1.450	1,731,000	1,657,000	11,380	632
2	"	1.445	1.520	1,556,000	1,528,000	10,330	574
3	"	1.469	1.448	1,765,000	1,732,000	10,710	595
4	"	1.420	1.498	1,736,000	1,636,000	10,830	601
5	"	1.450	1.485	1,688,000	1,578,000	11,980	665
6	"	1.480	1.440	1,795,000	1,686,000	11,040	613
7	"	1.464	1.460	1,682,000	1,561,000	10,570	587
8	"	1.420	1.480	1,647,000	1,556,000	11,280	626
9	"	1.460	1.460	1,704,000	1,638,000	11,180	621
10	"	1.441	1.460	1,616,000	1,550,000	12,440	691

In making the experiments, each beam was first subjected to a load of thirty pounds, and the deflection noted. The weight was then left on the beam for a period of time varying from one to four, and in one case forty-four hours, and the deflection again noted. The load was then removed from the beam and the set noted, after which the beam was allowed a certain time to recover from the set.

After the piece had returned, or at least nearly returned, to its original position, it was subjected to a load of forty pounds in the same manner.

Table II. gives the deflection of each piece under the loads of thirty and forty pounds, both immediately after the weight was applied and after it had rested upon the beam the length of time designated.

TABLE II.

No. of Test Piece.	Weight W.	Time applied.	Deflection Δ	E.	Weight W.	Time applied.	Deflection Δ	E.
	lbs.	h. m.	ins.	lbs.	lbs.	h. m.	ins.	lbs.
1	30	0 00	0.0610	1,744,000	40	0 00	0.0826	1,719,000
"	"	2 25	.0630	1,689,000	"	3 30	.0873	1,627,000
2	30	0 00	.0616	1,536,000	40	0 00	.0801	1,576,000
"	"	1 45	.0639	1,481,000	"	3 00	.0842	1,499,000
3	30	0 00	.0606	1,774,000	40	0 00	.0815	1,757,000
"	"	1 00	.0610	1,759,000	"	1 00	.0840	1,705,000
4	30	0 00	.0582	1,725,000	40	0 00	.0765	1,748,000
"	"	2 25	.0616	1,627,000	"	3 20	.0813	1,645,000
5	30	0 00	.0580	1,740,000	40	0 00	.0774	1,637,000
"	"	2 30	.0618	1,630,000	"	44 15	.0874	1,527,000
6	30	0 00	.0605	1,792,000	40	0 00	.0803	1,799,000
"	"	3 00	.0639	1,697,000	"	5 12	.0862	1,676,000
7	30	0 00	.0624	1,683,000	40	0 00	.0833	1,682,000
"	"	3 00	.0663	1,584,000	"	16 00	.0911	1,538,000
8	30	0 00	.0632	1,645,000	40	0 00	.0839	1,650,000
"	"	4 15	.0666	1,561,000	"	16 30	.0894	1,552,000
9	30	0 00	.0619	1,701,000	40	0 00	.0823	1,707,000
"	"	1 30	.0643	1,638,000	—	—	—	—
10	30	0 00	.0661	1,614,000	40	0 00	.0881	1,618,000
"	"	2 00	.0691	1,544,000	"	1 15	.0915	1,556,000

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The values of the Modulus of Elasticity calculated from these deflections are also given. The Moduli of Elasticity obtained from the deflection of the beams immediately after the weight was applied have been denoted by E, and those obtained from the deflection of the pieces after the weight had been applied one or more hours, by E_1. Table I. gives the values of E and E_1 for each piece, obtained by taking the average of the values given in Table II.

The values of E were computed by the formula $E=\frac{Wl^3}{4\triangle BD^3}$, in which W denotes the weight in pounds producing the deflection; l the clear span in inches; $\triangle$ the deflection of the beam at the center; B the breadth of the beam, and D the depth, both in inches.

After all the beams had been treated in this way, piece No. 3 was again put in the machine and subjected to a load of 100 lbs., which was allowed to remain upon the beam for about two hours, the deflection being measured directly after the weight was applied and just before it was removed. The beam was then allowed a certain time to recover its set. In two cases, the beams, after having been subjected to a load of 100 lbs., finally returned to their original position, and it appeared probable that all would have done so had sufficient time been allowed for the purpose.

After the piece had nearly recovered from the effects of the load of 100 lbs., a load of 150 lbs. was put on the beam, and gradually increased until the breaking point was reached.

The remaining pieces were tested with a load of 100 lbs. in the same way, and then subjected to a load of 400 lbs. for one or two minutes, for the purpose of getting the deflection under that load, and immediately after subjected to the full load of 500 lbs., which was gradually increased until the piece broke. As the load approached the breaking weight, it was increased by the addition of only one or two pounds at a time, so that the breaking weight could be obtained with sufficient accuracy. In fact, the breaking weight is so much modified by the time occupied in breaking the beam, that it is difficult to ascertain exactly what it really is. For any load over three-fourths of what is called the breaking weight would, probably, break the beam if applied long enough.

Table I. gives the values of the Modulus of Rupture of each piece, computed by the formula $R=\frac{3}{2}\frac{Wl}{BD^2}$, in which R denotes the Modulus of Rupture; W the breaking weight of the beam, and the other letters have the same significance as in the formula for E. The load which would break a beam of the same wood, one inch square and one foot between supports, if applied at the center, is also given in the same table. This load is one eighteenth of the Modulus of Rupture.

When the weight of 400 lbs. was applied to piece No. 7, it immediately cracked at a knarl in one of the lower edges, about three-fourths of an inch from the center of the beam. As it was thought that the beam would soon break entirely, the load of 400 lbs. was allowed to remain on the beam; but at the end of one hundred hours the deflection had only increased 0.2224 inches, and as it was evident that it would, at that rate, take a long time for the beam to break, the load was then gradually increased until the piece broke at 550 lbs., giving a Modulus of Rupture considerably above the average. It was noticed in this beam that the deflections under the loads above 500 lbs. were considerably greater than in the other beams under the same loads.

Piece No. 5 gave a very high breaking weight, and broke very suddenly, more like the harder kinds of wood. The fracture was very perfect, the upper half of the fibers being very evidently compressed and the lower half suddenly pulled apart, with almost no splintering. This piece had a small knot on the upper side, five inches from the center of the beam, but it appeared to have no effect upon the strength of the beam.

Piece No. 4 broke in a rather peculiar manner. While under a load of 575 lbs., the lower fibers for about a depth of one-tenth of an inch snapped apart, and the beam gradually settled down until the next layer of fibers had apparently the same deflection as did the lower ones at the time of breaking, when they also snapped, making a layer of about the same thickness. In this way the whole lower half of the beam seemed to divide

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itself into layers of about one-tenth of an inch thick, and to break separately under about the same deflection, so that the beam was a long time in breaking.

Observing that under every load that had been applied the deflection kept increasing with the length of time the weight remained on the beam, piece No. 7 was subjected to a load of 275 lbs. for ninety-eight hours, during which time the deflection increased 0.079 inches. The weight was then taken off and the beam allowed to recover for twenty-four hours, when it had a set of .0446 inches. The same weight was again applied, and it was found that the deflection, obtained by taking the difference between the readings of the micrometer just before and after the weight was applied, was less than it was the first time the weight was applied, and the rate of increase of the deflection was about the same as before. The beam was thus subjected to a weight of 275 lbs. for three hundred hours in all, after which it was broken in the same manner as the others. It was expected that the effect of such a severe strain for so long a time would diminish its strength; but, on the contrary, it appeared to increase it, as the beam gave a higher Modulus of Rupture than any of the others, although it did not appear to be of as good quality as many of them. The ultimate deflection of this beam greatly exceeded that in any of the others.

Table III. shows the deflection of each beam under loads of 30, 40, 100, 400, 500, and 550 lbs., immediately after the load was applied, and at a distance of one inch from the center. The small figures under each deflection show what it would be if Hooke's Law held true, taking the deflection under 30 lbs. as the starting point.

TABLE III.

No. of Test Piece.	Deflection in inches under						Ultimate Deflection	Breaki'g weight. lbs.
	30 lbs.	40 lbs.	100 lbs.	400 lbs.	500 lbs.	550 lbs.		
1	0.0610	0.0826	0.2071	0.8303	1.0906	1.2791	1.5646	588
	.0610	.0813	.2030	.8120	1.0150	1.1165		
2	.0616	.0801	.2043	.8177	1.0677	1.2811	1.3941	575
	.0616	.0820	.2050	.8200	1.0250	1.1275		
3	.0606	.0815	.2023	.8976	1.2764	1.4800*	1.4800*	550
	.0606	.0808	.2020	.8080	1.0100	1.1110		
4	.0582	.0765	.1929	.7929	1.1146	1.3197	1.4658	575
	.0582	.0776	.1940	.7760	0.9700	1.0670		
5	.0580	.0774	.2004	.7876	1.0170	1.1827	1.5788	637
	.0580	.0773	.1933	.7732	0.9665	1.0631		
6	.0605	.0803	.2138	....	1.2520	1.4662	....	565
	.0605	.0806	.2016	....	1.0080	1.1088		
7	.0624	.0833	.2083	.8961	1.3595	....	....	550
	.0624	.0832	.2080	.8320	1.0400	....		
8	.0632	.0839	.2102	.8315	1.1111	1.3331	1.5709	585
	.0632	.0842	.2106	.8424	1.0530	1.1583		
9	.0619	.0823	.2053	....	1.0800	1.2830	1.4254	580
	.0619	.0825	.2063	....	1.0315	1.1346		
10	.0661	.0884	.2220	.9276	1.1772	1.3775	1.8100*	637
	.0661	.0881	.2203	.8812	1.1015	1.2116		

From these experiments I think we may draw the following conclusions:

That the Modulus of Elasticity depends not only upon the elasticity of the material, but also upon the length of time the load is applied.

That when subjected to loads not exceeding one-sixth of the breaking weight, spruce beams do not take a permanent set

That even under very small loads, if applied for any length of time, there will be a temporary set.

That knots and knarls in beams loaded at the center, when not within one-eighth of the span of the center of the beam, do not materially affect the elasticity under small loads.

That the deflection is very nearly proportional to the load, far beyond the customary limits of strain, and that the

*Approximately.

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Modulus is consequently very nearly constant for all moderate deflections.

That a high Modulus of Elasticity does not always accompany high transverse strength; for, as shown by Table I., piece No. 10, which had the greatest transverse strength, gave next to the lowest value of E.

That in spruce beams the upper fibers commence to rupture by compression under about four-fifths of the breaking weight, and the neutral axis is very near the center of the beam as shown by the fracture.

That beams which are subjected to severe strains for a long time bend more before breaking than those which are broken in a comparatively short time.

That the Modulus of Elasticity of small spruce beams, of a quality such as is used in the best buildings, may be taken at from 1,600,000 to 1,700,000 lbs., and the Modulus of Rupture at about 11,000 lbs.

The only other experiments on American spruce with which the writer is familiar are those made by Mr. R. G. Hatfield on small beams, 1.6 feet between supports, and some experiments by Mr. Thomas Laslett, of England, on pieces of Canada spruce, 2 inches square and 72 inches between supports.

Mr. Hatfield gives as the average value of the transverse strength of a unit beam, 612 lbs..* which would give 11,016 lbs. for the Modulus of Rupture.

From data given by Laslett† we obtain as the value of R, 9,045 lbs.

The value generally given for the Modulus of Elasticity of spruce is 1,600,000 lbs.

GAS AND ELECTRICITY AS HEATING AGENTS.*

By Dr. C. WILLIAM SIEMENS, F.R.S.

From "Iron."

On the 14th of March, 1878, I had the honor of addressing you "On the Utilization of Heat and other Natural Forces." I then showed that the different forms of energy which Nature has provided for our uses had their origin, with the single exception of the tidal wave, in solar radiation; that the forces of wind and water, of heat and electricity, were attributable to this source, and that coal formed only a seeming and not a real exception to the rule—being the embodiment of a fractional portion of the solar energy of former geological ages.

On the present occasion I wish to confine myself to one branch only of the general subject, namely, the production of heat energy. I shall endeavor to prove that for all ordinary purposes of heating and melting gaseous fuel should be resorted to, but that for the attainment of extreme degrees of heat the electric arc possesses advantages, unrivaled by any other known source of heat.

Carbonaceous material such as coal or wood, is practically inert to oxygen at ordinary temperatures; but if wood is heated to 295° C. (593 Fah.), or coal to 326° C. (617° Fah.) according to experiments by M. Marbach, combination takes place between the fuel and the oxygen of the atmosphere, giving rise to the phenomenon of combustion. It is not necessary to raise the whole of the combustible materials to this temperature, in order to continue the action; the very act of combustion when once commenced gives rise to a great development of heat, more than sufficient to prepare additional carbonaceous matter, and additional air for entering into combination; thus a match suffices to ignite a shaving, and that in its turn to set fire to a building.

The first effect of combustion is, therefore to heat the combustible and the air necessary to sustain combustion to the temperature of ignition, but in dealing with the combustible called coal other preparatory work has to be accomplished, besides mere heating in order to sustain

* A lecture delivered before the Science Lecture Association, Glasgow.

* Hatfield's Transverse Strains, Table XLII.

† Timber and Timber Trees, Native and Foreign, by Thomas Laslett, Inspector to the Admiralty, London, 1875.

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combustion. The following is an analysis from Dr. Percy's work on "Fuel" of a coal from the Newcastle district:

Carbon	81.41
Hydrogen	5.83
Oxygen	7.90
Nitrogen	2.05
Sulphur	0.74
Ash	2.07

which shows at a glance that nearly 16 per cent. of the total weight consists of such permanent gases as hydrogen, oxygen and nitrogen. Those gases are partly occluded or absorbed within the coal, but are also combined with carbon forming volatile compounds, such as the hydrocarbons and ammonia, so that when coal is subjected to heat in a closed retort, as much as 35 per cent. passes away from the retort in a gaseous condition and as vapor of water, partly to condense again in the form of tar, and of ammoniacal liquor, and partly to pass into the gas mains as illuminating gas, a mixture merely of marsh gas (CH_4), olefiant gas (C_2H_4), and acetylene (C_2H_2), its value as an illuminant depending upon the percentange of the last two constituents rich in carbon. The result of the distillation of a ton of coal will be as follows, from data with which Mr. A. Upward has kindly supplied me:

	Cwt.
Cake	13.60
Tar	1.20
Ammoniacal liquor	1.45
Gas	3.15
Carbonic acid	0.18
Sulphur removed by purifying	0.30
Loss	0.12

So great is the loss of heat sustained in an ordinary coal fire, in consequence of the internal work of volatilization, that such a fire is scarcely applicable for the production of intense degrees of heat, and it has been found necessary to deprive the coal in the first place of its volatile constituents (to convert it into coke) in order to make it suitable for the blast furnace, for steel melting, and for many other purposes where a clear intense heat is required.

In the ordinary coke oven the whole of the volatile constituents are lost, and each 100 lbs. of coal yield only 66 lbs. of coke, including the whole of the earthy constituents which on a large average may be taken at 6 lbs., leaving a balance 60 lbs. of solid carbon. In burning these 60 lbs. of pure carbon, 220 lbs. of carbonic anhydride (CO_2) are produced, and in this combination $60 \times 14{,}500 = 870{,}000$ heat units (according to accurate determinations by Favre and Silbermann, Dulong and Andrews) are produced.

The 34 per cent. of volatile matter driven off yield, when the condensible vapors of water, ammonia and tar, are separated, about 16 of pure combustible gas (being equal to about 10,000 cubic feet per ton of coal) which in combustion produce $16 \times 22{,}000 = 352{,}000$ heat units. The escape of these gases from the coke oven constitutes a very serious loss, which may be saved, to a great extent at least, if the decarburization is effected in retorts. The total heat producible from each 100 lbs. of coal is in that case $870{,}000 + 352{,}000 = 1{,}222{,}000$ or 12,220 units per lb. of coal. Deduction must, however, be made from this for the heat required to volatilize 34 lbs. of volatile matter for every 100 lbs. of coal used, and also for heating the coke to redness, or say to 1,000° Fah. Considering the multiplicity of gases and vapors produced it would be tedious to give the details of this calculation, the result of which would approximate to 60,000 heat units, or 600 units per lb. of coal treated.

We thus arrive at $12{,}200 - 600 = 11{,}600$ heat units as the maximum result to be obtained from 1 lb. of best coal. Considering, however, that the coal commonly used for industrial purposes contains more ashes and more water than has been here assumed, a reduction of say 10 per cent. is necessary, and the calorific power of ordinary coal may fairly be taken at 10,500 units per lb.

In applying this standard of efficiency to actual practice it will be found that the margin for improvement is large indeed. Thus, in our best steam-engine practice we obtain one actual horse-power with an expenditure of 2 lbs. of coal per hour (the best results on record being 1.5 lbs. of coal per indicated horse-power.) A horse-power represents $33{,}000 \times 60 = 1{,}980{,}000$ foot-lbs. per hour, which is $\frac{1{,}980{,}000}{2} = 980{,}000$ foot-lbs., or units of force, per lb. of fuel. Dr. Joule has shown us that 772 foot-lbs. represent one unit of heat, and 1 lb. of coal therefore produces $\frac{980{,}000}{772} = 1{,}282$ units

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of heat, instead of 10,500, or only one-eighth part of the utmost possible result.

In melting steel in pots in the old-fashioned way, as still practiced largely at Sheffield, 2½ tons of best Durham coke are consumed per ton of cast steel produced. The latent and sensible heat really absorbed in a pound of steel in the operation, does not exceed 1,800 units, whereas 2½ lbs. of coke are capable of producing $13{,}050 \times 2.5 = 32{,}625$ units or 18 times the amount actually utilized.

In domestic economy the waste of fuel is also exceedingly great, but it is not easy to give precise figures representing the loss of effect, owing to the manifold purposes to be accomplished, including cooking and the heating and ventilation of apartments. If ventilation could be neglected close stoves, such as are used in Russia, would unquestionably furnish the most economical mode of heating our apartments; but health and comfort are, after all, of greater importance than economy, and these are best secured by means of an open chimney. Not only does the open chimney give rise to an active circulation of air through the room, which is a necessity for our well-being, but heat is supplied to the room by radiation from the incandescent material instead of by conduction from stove surfaces; in the one case the walls and furniture of the room absorb the luminous heat rays, and yield them back to the transparent air, whereas, in the latter case, the air is the first recipient of the stove heat, and the walls of the room remain comparatively cold and damp, giving rise to an unpleasant musty atmosphere, and to dry rot or other mouldy growth. The adversaries of the open fireplace say that it warms you on only one side, but this one-sided radiant heat produces upon the denizens of this somewhat humid country, and indeed upon all unprejudiced people, a particularly agreeable sensation; which is proof, I think, of its healthful influence. The hot radiant fire imitates, indeed, the sun in its effect upon man and matter, and before discarding it on the score of wastefulness and smokiness, we should try hard, I think, to cure it of its admitted imperfections.

If incandescent coke is the main source of radiant heat, why, it may be asked, do we not resort at once to coke for our domestic fuel? The reasons are twofold; the coke would be most difficult to light, and when lighted would look cheerless without the lively flickering flame.

The true solution consists, I venture to submit, in the combination of solid and gaseous fuel when brought thoroughly under control, by first separating these two constituents of coal. I am bold enough to go so far as to say that raw coal should not be used as fuel for any purpose whatsoever, and that the first step toward the judicious and economic production of heat is the gas retort or gas producer, in which coal is converted either entirely into gas, or into gas and coke, as is the case at our ordinary gas works.

When in the early part of the present winter London was visited by one of its densest fogs, many minds were directed towards finding a remedy for such a state of things. In my own case it has resulted in an arrangement which has met with a considerable amount of favor and practical success, and I do not hesitate to recommend it to you also for adoption. Its general application would, as regards dwelling houses, make our town atmosphere as clear as that of the surrounding country. If it can be shown that the arrangement may be easily and cheaply applied, that it will relieve our housemaids of the most irksome portion of their daily work in laying fires and cleaning grates, and that a warm and cheerful fire can be made at a considerably cheaper rate than when using coal, you will admit, I hope, that the proposal is worthy of a trial.

In outward appearance my fire-grate—which I have not made the subject of a patent, and which may, therefore, be put up by any grate or gas fitter without restraint—is very similar to the ordinary coal grate; the latter may, indeed, be converted into the smokeless grate at a very trifling cost. The essential features of this grate are, that solid carbonaceous fuel, such as coke or anthracite, are used in combination with as much gas as is found necessary to raise the former to the point of incandescence; that the combustion is entirely confined to the front of the grate, whence radiation into the room takes place; and that any heat

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reaching the back of the grate is conducted away and utilized in heating the incoming air, by which combustion in front of grate is supported. In this way greater brilliancy and considerable economy are realized.

In one arrangement by which this is effected an iron dead plate is riveted to a stout copper plate facing the back of the fire grate, and extending 5 inches both upwards and downwards from the point of junction. The dead plate stops short about an inch behind the bottom bar of the grate to make room for a half-inch gas pipe, which is perforated with holes of about one-sixteenth of an inch placed at a distance of 1½ inches along the inner side of its upper surface. This pipe rests upon a lower plate, which is bent downwards towards the back, so as to provide a vertical and horizontal channel of about 1 inch in breadth between the two plates. A trap door, held up by a spring, is provided for the discharge of ashes falling into this channel. The vertical portion of this channel is occupied by a strip of sheet copper about 4 inches deep, bent in and out like a lady's frill, and riveted to the copper back piece.

Copper being an excellent conductor of heat, and this piece presenting (if not less than a quarter of an inch thick) a considerable sectional conductive area, transfers the heat from the back of the grate to the frill work in the vertical channel. An air current is set up by this heat, which, in passing along the horizontal channel, impinges on the line of gas flames, and greatly increases their brilliancy. So great is the heat imparted to the air by this simple arrangement, that a piece of lead of about half a pound in weight introduced through the trap door into this channel melted in five minutes—proving a temperature exceeding 619° Fah., or 326° C. The abstraction of heat from the back has, moreover, the advantage of retarding the combustion of the coke there while promoting it at the front of the grate.

I have used this arrangement in a fireplace at my office, in a room of 7,200 cubic feet capacity facing the north. I always found it difficult, during cold weather, to keep this room at 06° Fah. with a coal fire; but it has been easily maintained at that temperature since the grate has been altered to the gas-coke grate just described.

In order to test the question of economy, I have passed the gas consumed in the grate through a Parkinson's 10-light dry gas meter supplied to me by the Woolwich, Plumstead and Charlton Consumers' Gas Company. The coke used is also carefully weighed.

The result of one day's campaign of nine hours is a consumption of 62 cubic feet of gas and 22 lbs. of coke (the coke remaining in the grate being in each case put to the debit of the following day). Taking the gas at the average London price of 3*s.* 6*d.* per 1,000 cubic feet, and the coke at 18*s.* a ton, the account stands thus for nine hours:

62 cubic feet of gas at 3*s.* 6*d.* per thousand	2.604 *d.*
22 lbs. of coke at 18*s.* a ton	2.121
Total	4.725

or at the rate of 0.525*d.* per hour. In its former condition at a coal grate the consumption exceeded generally two and a-half large scuttles a day, weighing 19 lbs. each, or 47 lbs. of coal, which at 23*s.* a ton equals 5.7*d.* for nine hours, being 0,633*d.* per hour. This result shows that the coke-gas fire, as here described, is not only a warmer but a cheaper fire than its predecessor; with the advantages in its lit without the trouble of laying the fire, as it is called, and keep alight without requiring to be stirred, that it is thoroughly smokeless, and that the gas can be put off or on at any moment, which in most cases means considerable enonomy.

A second and more economical arrangement as regards first cost consists of two parts which are simply added to the existing grate, viz.: (1) the gas pipe with a single row of hole of about 1-16 inch diameter, 1.5 inch apart along the upper side inclining inward, and (2) an angular plate of cast iron, with projecting ribs extending from front to back on its under side, presenting a considerable surface, and serving the purpose of providing the heating surface produced by the copper plate and frill work in my first arrangement. In using iron instead of copper it is necessary, however, to increase the thickness of these plates and ribs in the inverse ratio of the conductivity of the two metals, or as regards

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the back plate, from ¼ inch to ⅝ inch. An inclined plate, fastened to the lower grate bar, directs the incoming air upon the heating surfaces, and provides at the same time a support for the angular and ribbed plate which is simply dropped into its firm position between it and the back of the grate. The front edge of the horizontal plate has vandyked openings, forming a narrow grating, through which the small quantity of ashes, that will be produced by combustion of the coke or anthracite in the front part of the grate, discharge themselves down the incline towards the back of the hearth, where an open ash pan may be placed for their reception. In adapting the arrangement to existing grates, the ordinary grating may be retained to support the angular plate which has in that case its lower ribs cut short, to the level of the horizontal grate.

A considerable number of grates have now been constructed or altered in accordance with my plan, and have given great satisfaction to the users, on account of convenience and economy, which are conditions essentially necessary, if we are to make any way toward the more important, I may say national, result of a "smokeless London," a smokeless Manchester, and a smokeless Glasgow. But it may be asked, are you sure that the coke and gas grate you advocate, will do away with fogs and smoke? My answer is, that it would certainly do away with smoke, because the products of combustion passing away into the chimney are perfectly transparent. Mr. Aitken has, however, lately proved in an interesting paper read before the Royal Society of Edinburgh, that even with perfect combustion a microscopic dust is sent up into the atmosphere, each particle of which may form a molecule of fog. We have evidence, indeed, that the whole universe is filled with dust, and this is, according to Professor Tyndall, a fortunate circumstance, for without dust we should not have a blue but a pitch black sky, and on our earth we should be, according to Mr. Aitken, without rain, and should have to live in a perpetual vapor bath. The gas fires would contribute, it appears, to this invisible dust, and we should, no doubt, continue to have fogs, but these would be white fogs, which would not choke and blacken us.

Granted the cure of smoke, it might still be questioned whether such a plan as here proposed could be carried out, on so large a scale as to affect our atmosphere, with the existing mains and other plant of the gasworks. If gas were to be depended upon entirely for the production of the necessary heat, as is the case with an ordinary gas and asbestos grate, it could easily be proved that the existing gas mains would not go far to supply the demand; each grate would consume from 50 to 100 cubic feet an hour, representing in each house a consumption exceeding many times the supply to the gaslights. My experiments prove, however, that an average consumption of from 6 to 8 cubic feet of gas per hour suffices to work a coke-gas grate, on the plan here proposed. This is about the consumption of a large Argand burner, and therefore within the limits of ordinary supply. But, independently of the practical question of supply, it is desirable on the score of economy to rely upon the solid carbon chiefly for the production of radiant heat, for the following reason:

1,000 cubic feet of ordinary illuminating gas weigh 34 lbs., and the heat developed in their combustion amounts to $34 \times 22{,}000 = 748{,}000$ heat units.

One pound of solid coke develops in combustion, say, 13,400 heat units (assuming 8 per cent. of incombustible admixture) and it requires $\frac{748{,}000}{13{,}400} = 56$ lbs., or just half a hundred weight, of this coke to produce the same heating effect as 1,000 cubic feet of gas. But 1,000 cubic feet of gas cost on an average 3*s.* 6*d.*, and a half hundred weight of coke not more than 6d. (at 20*s.* a ton), or only one-seventh part of the price of gas.

If heating gas was supplied at a much cheaper rate it would, in many cases, be advantageous to substitute incombustible matter, such as balls of asbestos for the coke or anthracite. The consumption of gas would in that case have to be increased very considerably, but the economical principle involved (that of heating the air of combustion by conduction from the back of the grate) would still apply, and produce economical results as compared with those obtained by the gas-asbestos arrangements

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hitherto used. To illustrate the efficiency of this mode of heating the incoming air by what is called waste heat, I will show you another application of the same principle which I have made very recently to the combustion of gas for illuminating purposes.

Gas engineers have been under the impression until now that a supply of cold air was favorable to the production of a brilliant flame. This is a misconception which was very general also as regards the combustion of solid fuel in furnaces, until it was disproved by Stirling, by Neilson, and by the introduction of the regenerative gas furnace. The "duplex burner" owes its brilliancy to the heating effect of the one burner upon the other; and my brother, Mr. Frederick Siemens, has more recently constructed a burner in which the flame of the gas is reversed in its action in order to heat in its descent the ascending current of flame-supporting air. By the application of the principle of conduction before described, I obtain the hot-air current in the most simple manner without interfering with the free action of the flame. In my arrangement an ordinary Argand burner takes its supply of gas through an enlarged vertical copper tube. This copper pipe terminates in a rod of highly conductive copper, which passes upward through the burner, and carries at its top a ball of porcelain or other refractory material. The rod is coated with platinum or nickel to prevent oxidation when heated (almost to redness) by the heat of the flame. The tube is armed with radial plates of copper presenting a considerable aggregate surface, and abutting externally against a covering of asbestos or other non-conductive material.

The waste heat of the flame, or that portion of the heat produced in combustion which is not utilized in luminous rays, serves to heat the ball of refractory material and the conductive rod. The heat is thus transferred by conduction to the upright copper tube, with its laminar radii, between the extensive surfaces of which currents of air are free to ascend towards the Argand burner. The air is thus heated to from 700° to 800° Fah. before meeting the gas, and the ultimate temperature of the flame is increased to at least the same amount, causing a larger proportion of the heat developed in combustion to reach the point of luminous radiation. But not only the quantity of light, but its quality, is improved by the higher temperature obtained. It may appear surprising, but it is a fact susceptible of accurate proof, that the light obtained in consumption of a given amount of gas may thus be increased by some 40 per cent., and that in this large proportion the deleterious influences connected with gas lighting may be diminished. Gas will thus be better able to hold its position against its more brilliant rival the electric light, except for such large applications as the lighting of public halls and places, of harbor, railway stations, warehouses, &c., for which it is pre-eminently suited. Add to these improved applications of gas the ever-increasing ones for heating purposes, and I have only to express regret that I am not a gas shareholder. If gas is to be largely employed, however, for heating purposes, it will have to come down in price; and considering that heating gas need not be highly purified, or possessed of high illuminating power, the time will come, I believe, when we shall have two services, one for illuminating and the other for heating gas.

In many towns two systems of gas mains already exist; and it would only be necessary to appropriate the one for illuminating and the other for heating gas. The ordinary retorts could be used for the production of both descriptions of gas, it being well known that even ordinary coal will give up gases of high illuminating power during a certain portion of the time occupied in their entire distillation. The gases emitted from the retort when first charged are to a great extent occluded gases of low illuminating power such as fire damp or marsh gas, and these should be turned into the heating mains. In the course of half an hour these occluded gases, together with the aqueous and other vapors will have left the coal, which is then in the best condition to evolve olefiant gas and other gases rich in carbon, and therefore of higher illuminating power. The period during which such illuminating gases are emitted extends over probably two hours, after which the retorts should again be connected with the heating gas mains, until the end of the process. The result

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of this *modus operandi* would be that the illuminating gas supplied, say in London, from Newcastle coal, would probably exceed 20-candle power, instead of 16, as at present, whereby the objectionable results of gas lighting would be greatly diminished, and there would be, say, an equal volume of heating gas available, consisting for the most part of marsh gas, which, although greatly inferior to olefiant gas in illuminating effect, would be actually more suitable for heating purposes, because less liable to produce soot in its combustion.

The total cost of production would not be increased by this separation of the gases, and the price might, with advantage both to the supplier and to the consumer, be so adjusted that the latter, while paying for his illuminating gas an increased price proportionate to the increase of illuminating power, would be furnished with a heating gas at greatly reduced cost; for the heating gas would be reduced in price in a much larger proportion than the illuminating gas would have to be raised, because it would not require the same purification from sulphur which renders illuminating gas comparatively costly. The enormous increase of consumption would moreover enable the gas companies to reduce prices all round very considerably without interfering with their comfortable revenues.

For large applications of heating gas to the working of furnaces and boilers, simpler means than the retort can be found for its production. I constructed a gas producer many years ago in connection with my regenerative gas furnace, which I need not now describe in detail. In it all the carbonaceous matter of the coal is converted into combustible gas, the solid carbon yielding a supply of carbonic oxide; the resultant mixture of combustible gas contains a very large proportion, averaging 61.5 per cent., of nitrogen, which swells its volume without in any way contributing to its heating power. It has been my endeavor for some time to construct a gas producer which, without losing the simplicity of the first, should be capable of yielding a heating gas of superior calorific power. This producer consists of a wrought-cylindrical chamber, truncated downwards, and lined with brickwork. The fuel to be converted into gas is introduced through a hopper, and the cinder and ashes work out through the open orifice at the bottom.

Instead of a grating for the introduction of atmospheric air a current of heated air is brought in, either through the hopper or through the orifice at the bottom, and is discharged into the center of the mass of fuel; the effect is the generation of a very intense heat at that point. The fuel, after its descent through the hopper, arrives gradually at this region of intense heat, and when subjected to it, parts with its gaseous constituents. At the point of maximum heat coke is consumed, producing carbonic anhydride, which, in passing through the considerable thickness of fuel surrounding this portion, takes up a second equivalent of carbon and becomes changed into carbonic oxide. Here also the earthy constituents are for the most part separated in a fused or semi-fused condition, and in descending gradually reach the orifice at the bottom, whence they are removed from time to time. Air enters through the bottom orifice to some extent, causing the entire consumption of the carbonaceous matter, which may have got past the zone of greatest heat; water is also here introduced in a hollow tray, and after evaporation by the heat of the hot clinkers, passes upwards through the incandescent mass, and is converted by decomposition into carbonic oxide and hydrogen gas. The exit orifices for the gases are placed all round, near the circumference of the chamber, ascending upwards into an annular space, whence they are taken through pipes to the furnace or other destination. The advantages connected with this *modus operandi* consists in the intensity of the heat produced within the center of the mass, whereby the whole of the fuel is converted into combustible gases, with the least amount of nitrogen. The hydrocarbons formed in the upper portion of the apparatus have to descend through the hotter fuel below, and in so doing, the tar and other vapors mixed up with them are decomposed, and furnish combustible gases of a permanent character.

The orifice at the bottom of the apparatus may be enlarged and so arranged that, instead of ashes only being produced, coke may be withdrawn, and in

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this way a continuous coke oven may be constructed, which is at the same time a gas producer, or, in other words, an apparatus in which both the solid and gaseous constituents of the coal are fully utilized. The intense heat in the very center of a large mass of fuel has for its result a very rapid distillation, and thus one gas producer does the work of two or three gas producers of the type hitherto employed; this more concentrated action will moreover allow of the introduction of gaseous fuel, where want of space and considerations of economy have militated hitherto against it, and in favor of the ordinary coal furnace. It has been already proved that steam boilers can be worked economically on land with gaseous fuel, and there is no reason that I know of why the same mode of working should not also be applied to marine boilers. The marine engine has within the last fifteen years been improved to an extent which is truly surprising; the consumption of coal, which at the commencement of that period was never less than 8 lbs. per horse power, has been reduced by expansive working in compound cylinders to 2 lbs. or even less per actual horse-power. The mode of firing marine boilers has, however, remained the same as it was in the days of Watt and Fulton. In crossing the Atlantic one may see a considerable number of men incessantly employed in the close stoke hole of the vessel opening the fire doors and throwing in fuel. Each charge gives rise to the development of great clouds of black smoke issuing from the chimney, to the great annoyance and discomfort of the passengers on deck. If, instead of this, the fuel could be discharged mechanically into one or more gas producers, the gaseous fuel produced would maintain the boilers at a very uniform heat, without necessitating the almost superhuman toil of the firemen; no smoke or dust would be emitted from the chimney, and a large saving of fuel would be effected.

This change would be specially appreciated by the numerous tourists visiting the Western Highlands. Speaking from my own experience on one occasion, I may say that the pleasure of a trip on the beautiful Loch Lomond was very seriously marred in consequence of the fumigation which my fellow-passengers and myself had to endure. The change from the use of solid to gaseous fuel would be the prelude probably to another, and still more important change, namely, the entire suppression of the steam boiler. We are already in possession of gas engines working at moderate expense as compared with small steam engines, even when supplied with the comparatively expensive gas from our town gas mains, and all that will be required is an extension of the principle of operation already established. The realization of such a plan would, of course, involve many important considerations, and may be looked upon as one of those subjects the accomplishment of which may be left for the energy and inventive power of the rising generation of engineers.

Before leaving this branch of the subject, I wish to call attention to a favorite suggestion which I had occasion to make some years ago. It consists in placing gas producers at the bottom of the coal mines themselves, so that instead of having to raise the coal by mechanical power, the combustible gases ascending from the depth of the mine to the surface would acquire by virtue of their low specific gravity such an onward pressure that they could be conducted in tubes to distances of many miles, thus saving the cost of raising and transporting the solid fuel. Glasgow, with its adjoining coal fields, appears to me a particularly favorable locality for putting such a plan to a practical trial, and the well-known enterprise of its inhabitants makes me sanguine of its accomplishment. When thus supplied with gaseous fuel, the town would not only be able to boast of a clear atmosphere, but the streets would be relieved of the most objectionable portion of the daily traffic.

I now approach another and the last portion of my address, the attainment of very intense degrees of heat either for effecting fusion or chemical decomposition. Although by means of the combustion of either solid or gaseous fuel heats are produced which suffice for all ordinary purposes, there is a limit imposed upon the degree of temperature attainable by any furnace depending upon combustion. It has been shown by Bunsen and by St. Claire Deville, that at certain temperatures the

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chemical affinity between oxygen on the one hand and carbon and hydrogen on the other absolutely ceases, and that if the products of combustion CO_2 and H_2O be exposed to such a degree of temperature they would fall to pieces into their constituent elements. This point of dissociation, as it is called, is influenced by pressure, but has been found for CO_2 under atmospheric pressure to be 2600° C, (or 4700° Fahr.). But long before this extreme point has been arrived at, combustion is greatly retarded, and the limit is reached when the losses of heat by radiation from the furnace balance its production by combustion. To electricity we must look for the attainment of a temperature above that of dissociation, and we have evidence of the early application of the electric arc to such a purpose. In 1807 Sir Humphrey Davy succeeded in decomposing potash by means of an electric current from a Wollaston battery of 400 elements, and in 1810 he surprised the members of the Royal Institution by the brilliant electric arc produced between carbon points through the same agency. Magneto-electric and dynamo-electric currents allow of the production of the electric arc much more readily and economically than by the use of Sir Humphrey Davy's gigantic battery, and Messrs. Huggins, Lockyer and Liveing, and other physicists, have taken advantage of the comparatively new method to advance astronomical and chemical research with the aid of spectrum analysis.

My object is now to show that the heat of the electric arc is not only available within a focus, or extremely contracted space, but that it is capable of producing such larger effects as will render it useful in the arts for fusing platinum, iridium, steel, or iron, or for effecting such reactions or decompositions as require for their accomplishment an intense degree of heat, coupled with freedom from such disturbing influences as are inseparable from a furnace worked by the combustion of carbonaceous material. The apparatus which I employ to effect the electro-fusion of such material as iron or platinum consists of an ordinary crucible of plumbago, or other highly-refractory material, placed in a metallic jacket or outer casing, the intervening space being filled up with pounded charcoal or other bad conductor of heat. A hole is pierced through the bottom of the crucible for the admission of a rod of iron, platinum, or dense carbon, such as is used in electric illumination. The cover of the crucible is also pierced for the reception of the negative electrode, by preference a cylinder of compressed carbon of comparatively large dimensions. At one end of a beam supported at its center is suspended the negative electrode by means of a strip of copper, or other good conductor of electricity, the other end of the beam being attached to a hollow cylinder of soft iron free to move vertically within a solenoid coil of wire, presenting a total resistance of about 50 units or ohms. By means of a sliding weight the preponderence of the beam in the direction of the solenoid can be varied so as to balance the magnetic force with which the hollow iron cylinder is drawn into the coil. One end of the solenoid coil is connected with the positive, and the other with the negative pole of the electric arc, and, being a coil of high resistance, its attractive force on the iron cylinder is proportional to the electro-motive force between the two electrodes, or, in other words, to the electrical resistance of the arc itself.

The resistance of the arc was determined and fixed at will within the limits of the source of power, by sliding the weight upon the beam. If the resistance of the arc should increase from any cause, the current passing through the solenoid would gain in strength, and the magnetic force overcoming the counteracting weight, would cause the negative electrode to descend deeper into the crucible; whereas, if the resistance of the arc should fall below the desired limit, the weight would drive back the iron cylinder within the coils, and the length of the arc would increase, until the balance between the forces engaged had been re-established. Experiments with long solenoid coils have shown that the attractive force exerted upon the iron cylinder is subject only to slight variation within a range of several inches, which circumstance allows of a working range to that extent of nearly uniform action on the electric arc.

This automatic adjustment of the arc is of great importance to the attainment

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of advantageous results in the process of electric fusion; without it the resistance of the arc would rapidly diminish with increase of temperature of the heated atmosphere within the crucible, and heat would be developed in the dynamo-electric machine to the prejudice of the electric furnace. The sudden sinking or change in electrical resistance of the material undergoing fusion would, on the other hand, cause sudden increase in the resistance of the arc, with a likelihood of its extinction, if such self-adjusting action did not take place.

Another important element of success in electric fusion consists in constituting the material to be fused the positive pole of the electric arc. It is well known that it is at the positive pole, that the heat is principally developed, and fusion of the material constituting the positive pole takes place even before the crucible itself is heated up to the same degree. This principal of action is of course applicable only to the melting of metals and other electrical conductors, such as metallic oxides, which constitute the materials generally operated upon in metallurgical processes. In operating upon non-conductive earth or upon streams of gases, it becomes necessary to provide a non-destructible positive pole, such as is supplied by the use of a pool of fused platinum, or iridium, or by a plumbago crucible. In working the electric furnace, some time is taken up in the first instance in raising the temperature of the crucible to a considerable degree, but it is surprising how rapidly an accumulation of heat takes place. In using a pair of dynamo-machines capable of producing seventy webers of current with an expenditure of 7 horse-power, and which, when used for purposes of illumination, produce a light of 12,000 candles, a crucible of about 8 inches in depth, immersed in a non-conductive material, has its temperature raised to a white heat in fifteen minutes, and 4 lbs. of steel are fused within another fifteen minutes, successive fusions being effected in somewhat diminishing intervals of time. The process can be carried on on a still larger scale by increasing the power of the dynamo-machines and the size of the crucibles.

The purely chemical reaction intended to be carried into effect within the crucible might be interfered with through the detachment of particles from the dense carbon used for the negative pole, although its consumption within a neutral atmosphere is exceedingly slow. To prevent this I have used, both in this connection and also in the construction of electric lamps, a water pole, or tube of copper, through which a current of water circulates, so that it yields no substance to the arc. It consists simply of a stout copper cylinder closed at the lower end, having an inner tube penetrating to near the bottom for the passage of a current of water into the cylinder, which water enters and is discharged by means of flexible india-rubber tubing. This tubing being of non-conductive material, and its sectional area small, the escape of current from the pole to the reservoir is so slight that it may be neglected. On the other hand, some loss of heat is incurred through conduction, with the use of the water pole, but this loss diminishes with the increasing heat of the furnace, inasmuch as the arc becomes longer, and the pole is retired more and more into the crucible cover.

In the experiments which I shall now place before you the current which has supplied the one electric lamp in the center of the hall will be diverted by means of a commutator through the electric furnace. After it has been active for five minutes to warm the crucible, I shall charge it with 8 lbs. of broken steel files, which I shall endeavor to melt and pour out into an ingot mould before your eyes. By some obvious modifications of this electric furnace, it can be made available for a variety of other purposes where intense heat is required, combined with immunity from disturbing chemical actions. By piercing a number of radial holes through the sides of the chamber, and introducing the ends of wires through the same, an excellent means is provided of heating those wire ends very rapidly, without burning them, for the purpose of welding them together. The electrical furnace will also be found useful, I believe, in the hands of the chemist, to effect those high temperature reactions between gaseous bodies which require the employment of temperatures far exceeding the hitherto available limits, and will thus increase the area of available reactions at his dis-

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posal for the attainment of either scientific or practical ends.

I have endeavored to compress within the limited space of a single lecture subject matter that might occupy the close attention of the student for weeks or months; and I may, therefore, be pardoned if I have failed to convey to you more than a very rough outline of what may be accomplished by the judicious use of gaseous fuel, and of the electric current, as heating agents. The one purpose that has been foremost in my mind in preparing this lecture has been to make war upon the smoky chimney—which, so far from being a necessity under any circumstances whatever, should be regarded only as a remnant of that stage of our industrial and social progress which, satisfied with the attainment of certain ends could afford to neglect the economical and sanitary conditions under which those ends were accomplished. The exhibition, which has lately been held in this city, of appliances for heating and illuminating by means of gas and electricity, in which your President, my esteemed friend, Sir William Thomson, took so prominent a part—as he does in everything tending towards the advancement of human knowledge and well being—proves how deep is the interest felt amongst you in those very questions with which I have had to deal this evening. And so I thought you might not be disinclined to give attention once more to a particular view of the question, which happens to be the result of the independent labor of one who may claim, at any rate, to have given a life-long attention to the subject.

THE EFFECT OF PUNCHING ON STEEL AND IRON PLATES.

From "The Engineer."

We referred recently to certain experiments made by the Board of Trade on steel plates for boilers and ships. The most prominent feature in Mr. Trail's report is the absence of information on those points which most perplex engineers and shipbuilders; and before we have done we hope to make this fact very clear, in the hope that others will take new ground, and quit the beaten path of experiment, which, it may now be safely said, cannot lead us to a knowledge of that which we wish to know. It will be remembered that all the plates tested were pulled asunder by Mr. Kirkaldy, and the results obtained, although in many respects new to many persons, are just what were anticipated by those who have made steel a special subject of study. But, although this is true of most of the results obtained it is not true of all; and some of them are opposed in a small degree to those obtained by other inquirers. It is of the utmost importance that the effect produced on a plate by making holes in it should be understood very plainly. There are four ways in which a rivet hole may be made. It can be punched, or it can be drilled, or it can be punched first and drilled subsequently, or it can be first drilled, and then punched. The value of all the three first-named systems has been repeatedly tested, but no one has tested the fourth, and yet it appears to have much to recommend it. It is well known that when a plate is punched the hole is always a little conical, and this conical shape is of much value, because it relieves the rivet head or point to some extent of strain, and even though the head should fly off the rivet is still useful. Drilled holes are not conical, and this is admitted to be a serious objection to them, and besides they are expensive. Now, if plates requiring such holes were first drilled to, say, $\frac{3}{4}$ in., and then punched up to the proper dimensions, say 1 in., the cost of drilling would be reduced, and the conical punched hole would be obtained. It remains to be seen whether under such conditions the plate would or would not be weakened by the punching; as on this point we possess no information we must content ourselves with suggesting to any one about to test steel the advisability of trying what would be found a very simple experiment. As regards the other three systems, the Board of Trade

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carried out, as we have said, a number of experiments with results the general nature of which we have already indicated. They appear to show that when a plate is punched it loses strength, but that when punched and annealed, or punched and rimed out to size, or drilled, it gains in strength. Thus a ¼ in. plate which, unperforated, bore a strain of 30.7 tons per inch, bore 31.6 tons when punched and annealed, 31.23 tons when punched small and bored to size, and 31.46 tons when drilled. With a 1 in. plate the figures are 28.17 tons for the solid plate, punched 21.26, punched and annealed 29.12, punched small and bored to size 29.15, and drilled 28.43 tons; all the dies were about 20 per cent. larger in diameter than the punch. Putting these figures into percentages we have for the ¼ in. plate—the strength of the solid plate being 100—punched 93.8, punched and annealed 104.7, punched small and bored out 103.5, drilled 104.2; for the 1 in. plate the figures are 75.4, 103.3, 103.4, and 100.9. Here, again, we have ample corroboration of our often urged argument that the properties of thin steel plates do not form a guide to those of thick steel plates.

If we compare these results with others obtained at different times, and by other experimenters, it will be seen that some difference exists. Thus experiments made at Liverpool and Sheffield in 1878 showed that ¼ in. plates lost only about 8 per cent. by punching, which nearly agrees with the figures given above, while the 1 in. plates lose more than 33 per cent., instead of less than one-fouth, as given above. Again, according to the Board of Trade, steel plates ½ in. thick lost but 8.6 per cent. by punching, while in the experiments of which we speak the loss was found to reach as much as 26 per cent. We have here a very important disparity, and one which should be cleared up. Is it to be explained by differences in the quality of the steel, or by peculiarities in the system of testing employed? So far as we can see it depends entirely on the first condition, namely, the quality of the steel; and it should be remembered that in both cases the steels used were ostensibly the best that could be made. We find then that while the steel made by one firm will lose less than 9 per cent. by being punched, the steel made by another firm, at least as eminent, loses 26 per cent., or nearly three times as much. Furthermore, it is stated that the effect of punching is to deprive the metal of all power of stretching, and the consequence is that it breaks with a crystalline instead of with a fine silky fracture. Bearing these facts in mind, let us consider what light they throw on the peculiarities of steel. It is known that if a steel boiler plate be punched, the chances are about one hundred to one that cracks will start from all the rivet holes in the edges of the plate, if not from one to the other, almost before the riveting of the seam is completed. On the other hand, Lloyds permit steel ship plates to be punched and riveted up without riming or annealing, provided they are not more than ½ in. thick, and do not come under severe strains—garboard strakes, sheer strakes, and deck stringer plates must, if punched, be annealed or rimed. Leaving ships, however, and returning to boilers, we may say at once that no one dreams of putting a steel boiler together with punched holes, unless the plates are carefully annealed. On the other hand, scores of iron boilers are made with punched holes, and no cracking takes place, and the boilers are quite sound and good. To this it will be replied that iron does not lose strength by being punched, and that for that reason it may be punched with safety. It will, perhaps, be new to many of our readers, but it is none the less true, that this is a complete mistake. Iron boiler plates do lose in strength by punching. A set of experiments made in 1878 on best boiler plates ⅝ in. thick, such as are used for marine boilers of moderate size, showed that while the solid plate had a tensile strength of very nearly 20 tons per square inch, the metal lost in strength when punched with an open die, 22 per cent.; when punched with a close die, 20 per cent.; when punched and rimed, 11.4 per cent.; and when punched and annealed, 4 per cent. of its original strength. A second set of experiments on ostensibly a better class of "best best" plates as supplied to the Admiralty showed that under similar conditions the iron lost 18 per cent. of its strength by punching, and even when

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the holes were rimed the loss was 9.2 per cent., and when they were drilled 3 per cent. Here we see that although the loss is somewhat less than is the case with steel, it is nevertheless very considerable. But the injury inflicted on iron by punching does not seem to become apparent. The metal keeps its sorrows to itself. It shows no outward signs, and the 80 per cent. or so of strength left in the plate is always worth 80 per cent. But of the 80 per cent. or so left in steel no one can tell the value even approximately. Why is this? All the explanations which have been put forward to supply an answer will apply just as strongly to iron.

We are told that when a steel plate is punched, a ring of hard metal is left round the hole, which being compressed tends to split the plate, or prevents the strains being equally distributed through it.

Remove this hard ring with the rimer, or soften it by annealing, and the plate becomes as strong as ever. But does not all this hold good of punched iron? Is there not in its case a hard ring round the holes? Cannot this ring be rimed with the rimer or softened away by fire? The answer must be in the affirmative. The only feature indicating a different condition is that iron seems to be permanently injured to a small extent even by drilling, while steel is improved. The hard rings will not render an iron plate treacherous, while they make steel plates quite untrustworthy. Like causes, in a word, do not produce like effects; and to complicate the case still further, a Motala plate from Sweden, did not seem to lose any strength by being punched, plates .45 in. thick having an initial strength varying between 27 and 28 tons per inch before punching, and standing as much as 28.2 tons after punching.

We have little reason, then, to doubt that the true reason why punched steel plates will not answer for constructive purposes, while iron plates will answer, has yet to be sought out, and the inquiry must take two distinct directions. In the first place, we must have much more accurate analyses of steel to deal with than are now available, and chemists appear to be agreed that to make them they must operate on comparatively large quantities of the metal. It is very easy to speak, for instance, of .1 per cent. of carbon, but few persons realize what it is the chemist who seeks for this has to find. 0.1 per cent. of carbon means that a ton of steel contains 2.24 lbs. of carbon, each pound of the metal will contain 7 grains of carbon; and as the chemist operates on but a few grammes of the steel at a time, it will be seen how minute are the quantities of carbon, sulphur, and phosphorus with which he has to deal. But this would present no difficulty were it not that the analysis of iron, especially for carbon, is one of the most troublesome known, and we feel certain that many statements which now serve to perplex investigators struggling to arrive at the truth would be found erroneous if only accurate analyses were available. Again, the testing of steel plates in a machine is not a true test, because it specially eliminates the conditions under which steel suffers most, and is least trustworthy. Thus the strength of riveted steel joints should be ascertained by putting sudden strains on them, such as they may be supposed to suffer when a long ship is steaming head to wind in a heavy sea; and again, tests of boiler plates ought to be made with the plates hot, not cold. The inquiries which have been made up to the present are so misleading, that little or no regard is paid to them; and those who use steel freely rely entirely on their own practical acquaintance with it, and care little or nothing for the figures which exist in such multitudes. The great safeguard seems to be to deal for steel only with firms who have already supplied what has proved to be good. This is very hard, perhaps, on young firms; but it is not easy to see how it can be helped. If only steel did not now and then play those who use it false; if only it were not so susceptible of being deteriorated, that a change in the form of the ingot moulds has been known alone to suffice to render tons of steel next to useless, iron would cease to be made save for a few special purposes. The unsatisfactory aspect of the steel question as a whole is that we seem to make no progress, and that we know no more about it now than we did five years ago.

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THE OPTICAL DYNAMOMETER.

Translated from "l'Electricien."

In testing dynamo-electric machines it is a matter of considerable importance to determine the amount of work absorbed by the machine alone, without the intervention of other factors which are capable of affecting to an important extent the value of this work.

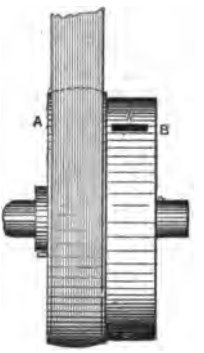

Fig.1

To measure the work with accuracy it is necessary to determine the tangential effort and the velocity at the point of application. The velocity is easily obtained by measuring the radius and counting the revolutions of the machine. The only difficulty is in measuring the tangential effort

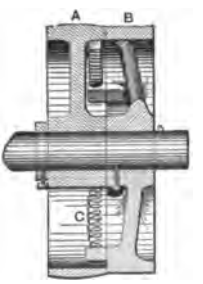

Fig.2

Different devices have been employed for this purpose. In some the difference in tension between the belt leading to the driving pulley and the belt leading from it has been measured. In others the effort of the driving pulley to turn the shaft has been measured by a spiral spring.

The dynamometer of M. Satchinoff presents the peculiarity of permitting the reading to be taken directly while the machine is in motion. The reading is made from graduations on the inner surface of a moving pulley, and is based on the principle of persistence of luminous impressions on the retina.

The figures 1 to 4 exhibit the plan of working of the apparatus. It consists of two pulleys, A and B, the former running loose upon the driving shaft, while B is keyed fast to it. The arms of the pulley A are attached to those of B by three spiral springs C, C, C. B is furthermore

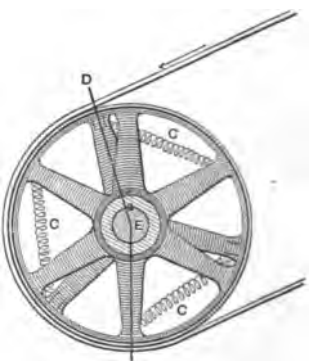

Fig.3

furnished with a rectangular slit R, through which the readings are made while the machine is in motion.

Under ordinary circumstances the driving belt is run on the keyed pulley B, and the shaft is then driven without any strain on the dynamometer. When a test of the power is required, the belt is run upon the pulley A, as shown in Fig. 4. The shaft is then driven through the agency of the springs, and there results a certain amount of angular displacement of the pulleys, the amount of which depends upon the effort required to overcome the resistance to be measured. The graduations on the inner surface of the pulley A serve to measure the displacement, and consequently the

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strain, by referring to the fixed reference point *n* on the edge of the pulley B.

The slit R is placed opposite to *n*, and may be read directly in pounds or kilograms.

This dynamometer is very simple, and

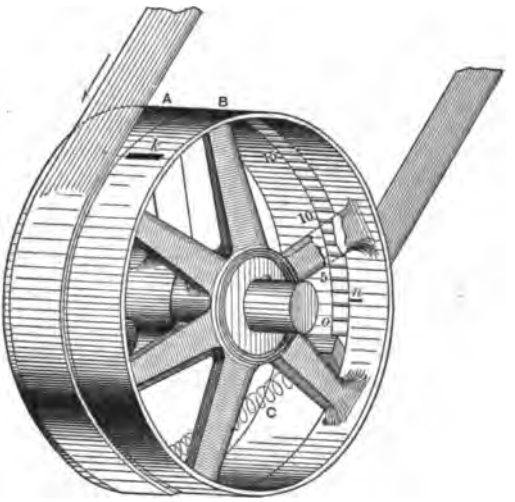

Fig. 4

permits *n* and the graduations to be plainly seen while the wheels are in rapid motion. By previous adjustment of the springs the force or resistance capable of a great variety of applications, and it is especially serviceable in cases of high velocity, a condition met with in all the dynamo-electric machines.

WEIGHT, SPECIFIC GRAVITY, RATES OF ABSORPTION AND CAPABILITIES OF STANDING HEAT OF VARIOUS BUILDING STONES.

By HIRAM A. CUTTING, Ph. D., State Geologist Vermont.

HAVING during the past year instituted, and carried out, a series of experiments to ascertain, as nearly as possible, the capabilities of the various materials used in the construction of so-called fireproof buildings to stand heat, I submit, in tabulated form, the result of such experiments, hoping they may be of use to the architects, quarrymen and Insurance companies of our country, and also of some interest to those interested in science.

In connection with the capabilities of the various building stones to stand fire and water, I have taken their specific gravity, and weight per cubic foot, so that the identity of the various stones could at any time be compared, and if in the working of a quarry there was a change in gravity, or weight, that it could be easily detected, and thus all who choose could know whether the tests given would apply or not.

I have procured sample specimens of the most important building stones in the United States and Canada, and, after dressing them into as regular form as possible, three by four inches, and two inches in thickness, I have taken their ratio of absorption, which ratio I have expressed in units of weight, according to the amount of water taken up. If 450 units of stone absorbed one unit of water, I have expressed it thus: 1+450, mean-

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ing that the stone weighed 450 units when immersed, and 451 when taken from the water.

To accelerate the process of absorption I have placed the specimens in water under the exhausted receiver of an air pump.

I find that in this way as much water is absorbed in a few minutes as in days of soaking. When specimens were removed from the water, I have, before weighing, dried their outsides with blotting paper. In relation to the specific gravity, I have not followed "Gilmore's" rule in full. He weighed the specimens in air, immersed them in water, and allowed them to remain until bubbling had ceased and then weighed them in water, after which he took them from the water, dried them outside with bibulous paper, and weighed them again in air. From this last weight he subtracted the weight in water, dividing the dry weight by the difference.

This gave a specific gravity subject to two sources of error. I have followed the more frequent custom of weighing the dry stone, using pieces of two or three pounds in weight, and then immersing them in water. After the usual saturation I have taken their weight in water, subtracting it from the dry weight in air, and then dividing the dry weight by the difference. This gives the specific gravity of the rock itself, as usually found, which is what we desire, and I believe as it would generally be in buildings constructed of the given material. The specimens were previously dried by long exposure to a temperature not exceeding 200° Fah. To verify this I have taken specimens from the quarries direct, and after weighing, have brushed them over with paraffine dissolved in naphtha, weighing them again so as to ascertain the exact amount of paraffine, which made no visible change in the stone, other than to keep out water. I have then weighed in the usual way, and thus obtained the exact specific gravity of the stone as in the quarry, and I find my method used, as stated, to give the best results, and so have adopted it.

After this I have placed them in a charcoal furnace, the heat of which was shown by a standard pyrometer. In many instances I have placed them side by side with dry specimens, but have been unable to note any marked difference in the action of heat, beyond this, that the dry specimens became sooner heated. I have, however, no doubt that the capacity of a stone to absorb water is against its durability, even in warm climates, and vastly more so in the changeable and wintry climate of New England. It is here often frozen before any considerable part of the moisture from Autumn rains can be evaporated.

When the specimens were heated to 600° Fah., I have immersed them in water, also immersing others, or the same, if uninjured, at 800° and 900°, that is if they are not spoiled at less temperatures. I find that all of these samples of building stones have stood heat without damage up to 500°. At 600° a few are injured; but the injury in many cases commences at or near that point. When cooled without immersion they appear to the eye to be injured less, but are ready to crumble, and I think they are many times nearly as much impaired, and always somewhat injured, when water produces any injury.

I would remark that my experiments with granites show that there is quite a range in their capabilities of standing heat, a range in fact much greater than I anticipated. With the sandstones the difference is also marked, as is their power of absorption. When exposed to the heat wet, they show a marked difference in the time required to heat them, the saturated ones seeming to resist the heat for a time; but when equally hot they crumble the same as those not previously saturated. Their relative worth can be seen by the table. The conglomerates stand heat badly; while the limestones and marble stand best of all (up to the point where they, by continued heat, are changed to quick lime) except soapstone, and a species of artificial stone made under the McMurtire & Chamberlain patent. The indications are, from this and other samples of artificial stone, that it may be possible to make an artificial stone cheaper and better for fireproof buildings than our native quarries furnish; and we hope this possibility may receive attention. But comments are useless, as the facts set forth in the tables speak for themselves.

I give you results in tabulated form on following pages:

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GRANITES.

No.	Kind.	Locality.	Specific gravity.	Weight of one cubic foot.	Ratio of absorption.	First appearance of injury.	Crumbles or cracks, slightly.	Cracks, badly, or becomes friable.	Injured so as to be worthless for a building.	Melted or ruined.
				lbs.		Deg. Fah.	Deg. Fah.	Deg. Fah.	Deg, Fah.	Deg. Fah.
1	Light colored	Hallowell, Me	2.638	164.8	1+790	800	900	950	1000	1100
2	"	Fox Island, Me	2.642	165.1	1+680	700	800	850	900	1000
3	Denning's Quarry	Mt. Desert, Me	2.631	164.1	1+716	800	850	950	1000	1100
4	Light colored	Rockford, Me	2.600	162.5	1+482	600	800	850	900	950
5	Red	Red Beach, Calais, Me	2.636	164.7	1+560	800	850	900	950	1000
6	Light colored	Oak Hill, Me	2.526	157.8	1+310	800	850	900	950	1000
7	Red	Stark, N. H	2.631	164.1	1+534	600	700	800	850	950
8	Colored medium	Concord, N. H	2.636	164.7	1+778	800	900	950	1000	1200
9	Sanborn's Quarry	Plymouth, N. H	2.649	165.5	1+685	800	900	950	1000	1200
10	Carter's Quarry	Ryegate, Vt	2.647	165.4	1+790	800	900	950	1000	1200
11	"	Woodbury, Vt	2.634	165.8	1+784	800	900	950	1000	1200
12	Wetmore & Morse's Quarry	Barre, Vt	2.651	165.6	1+720	800	900	950	1000	1200
13	Syenite	Quincy, Mass	2.660	166.2	1+650	750	800	850	900	1000
14	Gray	Croton, Conn	2.800	175.0	1+818	700	750	800	900	900
15	Common	Woodstock, Md	2.648	165.5	1+394	700	750	800	900	900
16	"	Port Deposit, Md	2.700	168.7	1+816	800	900	950	1000	1100
17	Scranton County Quarry	Richmond, Va	2.727	170.5	1+898	750	800	850	900	1000
18	Old Dominion Quarry	" "	2.674	167.7	1+402	750	800	850	900	1000
19	Light colored	St. Cloud, Minn	2.690	168.2	1+280	700	700	800	850	900
20	"	Stanstead, P. Q	2.883	177.0	1+420	800	900	1000	1000	1200
21	Coarse	North Halifax, N. S	2.698	168.6	1+584	700	800	800	900	900
22	"	Gananoque, P. O., Can	2.687	167.9	1+736	800	850	900	950	1000

LIMESTONE.

1	Limestone	Baltimore, Md	2.917	181.8	1+340	900	1000	1100	1200	1200
2	"	Bedford, Ind	2.478	154.8	1+280	850	900	1000	1200	1200
3	Cincinnati Limestone	Hamilton County, O	2.204	137.7	1+ 28	850	900	950	1200	1200
4	Potts Blue	Springfield, Penn	2.666	166.6	1+280	850	850	900	1000	1200
5	Dolomite Limestone	Owen Sound P. O	2.571	160.6	1+480	850	900	1100	1200	1200
6	Trenton Limestone	Montreal, P. Q	2.706	169.1	1+316	900	950	1000	1200	1200
7	Limestone	Isle La Motte, Vt	2.696	168.5	1+320	950	1000	1100	1200	1200

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SANDSTONE.

No.	Kind.	Locality.	Specific gravity.	Weight of one cubic foot.	Ratio of absorption.	First appearance of injury.	Crumbles or cracks, slightly.	Cracks, badly, or becomes friable.	Injured so as to be worthless for a building.	Melted or ruined.
						Deg. Fah.	Deg. Fah.	Deg. Fah.	Deg. Fah	Deg. Fah.
1	Freestone	Portland, Conn	2.380	148.7	1+ 27	850	900	950	1000	1100
2	"	North of England	2.168	135.5	1+ 27	850	900	950	950	1000
3	Seneca Stone	Montgomery Co., Md	2.500	156.2	1+ 26	850	900	900	950	950
4	Sandstone	Salem, Md	2.452	153.2	1+ 24	850	900	950	1000	1100
5	"	Seneca, Md	2.410	150.6	1+ 40	900	1000	1100	1200	1200
6	Montrose Stone	Ulster Co., N. Y.	2.661	166.3	1+314	900	1000	1100	1200	1200
7	Freestone	Belleville, N. J.	2.350	146.8	1+ 27	900	950	1000	1100	1100
8	"	Nova Scotia	2.424	151.5	1+240	900	950	1000	1100	1100
9	S. Carboniferous	Br. Phillipe, N. S.	2.353	147.0	1+ 19	900	950	950	1000	1000
10	Freestone	Dorchester, N. B.	2.363	147.7	1+ 26	800	850	900	1000	1000
11	Cincinnati Stone	Cincinnati, O.	2.188	136.1	1+ 23	900	950	1000	1100	1100
12	Potsdam Sandstone	McBride's Corners, O.	2.333	145.8	1+ 28	800	850	900	1000	1100
13	Berlin Stone	Cleveland, O	2.210	138.1	1+ 22	850	900	1000	1100	1100
14	Potsdam	McBride's Corners, O.	2.500	156.2	1+ 22	850	900	950	1000	1000
15	Euclid Stone	Near Cleveland, O	2.290	143.1	1+ 35	850	900	950	1000	1000
16	Berea Stone	Berea, O	2.254	140.8	1+ 20	850	900	950	1000	1000
17	Amherst Stone	Amherst, O	2.200	137.5	1+ 18	850	900	changes color.		1000
18	Brown Stone	Humbletown, Penn	2.346	146.6	1+ 28	850	900	950	1000	1000
19	Potsdam Sandstone	Beauharnois, P. Q.	2.512	157.0	1+ 38	850	900	950	1000	1000
20	Sandstone	Murray Bay, P. Q	2.577	161.0	1+ 36	900	950	1000	1100	1100
21	"	Cheat River, W. Va	2.632	164.5	1+ 80	800	850	900	1000	1100
22	Freestone	Acqua Creek, Va	2.183	136.4	1+ 16	900	950	1000	1100	1200
23	Brown Stone	Manasses, Va	2.348	146.7	1+ 17	850	900	1000	1100	1200

CONGLOMERATES.

1	Conglomerate	Roxbury, Mass	2.708	169.2	1+49	700	800	900	1000	1000
2	Potomac Stone	Point of Rocks, Md	2.724	170.2	1+60	600	700	800	900	900
3	Conglomerate	Cape a La Aisle, P. Q.	2.645	165.3	1+80	600	700	800	900	900

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MARBLES.

No.	Kind.	Locality.	Specific gravity.	Weight of one cubic foot.	Ratio of absorption.	First appearance of injury.	Crumbles or cracks, slightly.	Cracks, badly, or becomes friable.	Injured so as to be worthless for a building.	Melted or ruined.
						Deg. Fah.	Deg. Fah.	Deg. Fah.	Deg. Fah.	Deg. Fah.
1	Tuckahoe	Westchester Co., N. Y.	2.794	194.6	1+298	900	1000	1200	1200	1200
2	Ashley Falls	Ashley Falls, N. Y.	2.742	171.3	1+280	900	1000	1100	1200	1200
3	Snow Flake	Westchester Co., N. Y.	2.848	178.0	1+380	950	950	1000	1200	1200
4	Tennessee	Dougherty's Q'y, E. Tenn.	2.711	169.4	1+320	950	950	1000	1200	1200
5	Duke Marble	Near Harper's Ferry, Va.	2.812	175.7	1+340	1000	1000	1100	1200	1200
6	Black Marble	Isle La Morte, Vt.	2.682	176.6	1+320	1000	1000	1100	1200	1200
7	Sutherland Falls	Rutland, Vt.	2.666	166.6	1+342	1000	1000	1100	1200	1200

SLATES.

1	Sabin's Quarry	Montpelier, Vt.	2.869	179.3	1+110	800	850	900	1000	1200

SOAPSTONES.

1	Soapstone	Weathersfield, Vt.	2.668	166.7	1+3 8	1200	....	....	....	....

ARTIFICIAL STONE.

1	Artificial Stone	McMurtire & Chamberlain's patent	2.235	139.7	1+280	750	800	1100	1200	....

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OUR CENTER OF POPULATION.

By FRANK D. Y. CARPENTER, C. E.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

If a man in San Francisco and another living in New York should wish to hold a conference, it requires no mathematical demonstration to prove that the proper place for them to meet would be at a point half-way between these two cities. In this manner the burden of travel is shared equally between the two. But, if one man in San Francisco and two men in New York should desire to come together, the subject becomes more involved. It is evident that it would be unjust to require the solitary Californian to perform the entire journey across the Continent to meet his colleagues at their homes, and it would be equally unfair to oblige the two New Yorkers to travel half-way to San Francisco to confer with one person from there. The question is, how great a penalty should the former pay for his isolation, and how much benefit should the latter reap from their association?

An equitable compromise is effected by apportioning the distance in inverse ratio to the number of persons concerned. The one from San Francisco travels two-thirds of the distance while the two from New York come one-third. Thus, it will be observed, the amount of travel on each side of the rendezvous is equal; that is, one man journeys, say, two thousand miles, while the two accomplish one thousand each. In other words, to introduce from the science of mechanics a term which it will frequently be found convenient to use in this discussion, the moment of the man from San Francisco about the rendezvous is equal to the moment of the two men from New York with respect to the same point. The west moment is in equilibrium with the east moment, and the fulcrum about which they balance is the center of this population of three persons.

A moment is the product of a force by its shortest distance from some point, line or plane, to which it is referred, this distance being known as the leverage. The intensity of the force and the length of the leverage are counted in certain established units of weight and measurement. In the subject now under treatment the forces considered are the individuals of our population; and since all people, rich and poor, large and small, ignorant and learned, infant and adult, male and female, are of uniform importance in swelling the grand total of an enumeration, these forces are taken as of equal intensity, and their moments vary directly with the lengths of their lever-arms. In ordinary mechanical investigations the value of a moment is estimated in foot-pounds, the product being named from its component factors; a corresponding and appropriate term with which to measure the moments of this special discussion would be "mile-men."

If, now, with the one Californian and the two New Yorkers aforesaid, we combine groups of three from Chicago, four from New Orleans, and, to make the problem still more complicated, five from the central city of Saint Louis, it is still possible to find, by the appliance of well-known principles in mechanics, some point at which they could assemble with justice to all, and that would be the center of this population of fifteen souls. It is only necessary to assume a center, draw a system of rectangular axis through this point, find the moments of the fifteen persons with regard to each of these two lines, note the preponderance of moments on one side of each of the axis, divide this surplusage by the entire population under discussion, and the result will be the amount of displacement of the axis from its rightful position. Adjust these lines so as to compensate for that error, and their intersection will be at the true center of population.

This is the general method to be employed in finding the center of population of the country at large. But as it would be an infinite labor to consider its fifty millions of inhabitants individually, determining their moments one by one, it becomes necessary to handle them by groups, such as states, counties, town-

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ships, or square degrees, proceeding upon the assumption that the people of each of these groups are massed either in the geometrical center of the area occupied by them, or at some other point which, from an inspection of the map, aided, perhaps, by local calculations, seems to be their population center. Whatever divisions of area may be adopted for this purpose, it is always well to obtain separately the moments of those cities which, owing to size or remoteness from either axis of co-ordinates, will exert most influence on the center; the gain in accuracy will more than repay for the extra trouble incurred.

The center of population of the United States may, therefore, be defined as that point at which, if all of the people should assemble there, the amounts of travel performed on any two sides would balance; in less popular language, the moments of the population with respect to any great circle passing through that point, taken as an axis, are in equilibrium. It may sound strange to call an arc of a circle an "axis," but in the treatment of a new subject like this, it is permitted to take some liberties with language; in the words of King John to Katharine: "We are the makers of manners."

A knowledge of the whereabouts of this pivotal point is useful in various ways. It has a practical value in the location of a national capital, university, industrial fair, or other institution whose situation should be central and equally convenient of access on all sides. To the historian and political investigator its successive positions, as shown by census after census, graphically exhibit the movement and advance of our people in a wave which is at one time accelerated by the settlement of the Pacific coast, in the next decade checked by the loss of life and enterprise incident to our civil war, deflected to the North in 1870 by the excessive devastation of the Southern States; again to the South in 1880 by the rapid recovery and growth of that desolated region, and probably to be turned northward again in 1890 by the occupation of the region to be opened by the Northern Pacific Railway, and by a rush of emigration to the mineral regions of Alaska, and the establishment of a territorial government there. Through all of these vicissitudes, however, there is a constant progress to the West, and, its recurring positions upon a map being ordinarily symbolized by a star, this conventional sign becomes literally the star of empire of whose westward way so much is written and said. It is now in Ohio.

The center of the population of any portion of the earth's surface has been aptly compared to the center of gravity of a spherical shell of equal extent, having weight, in any locality, in proportion to the density of its population; but for tunately the determination of the former center is not so intricate a problem as that of the latter would prove to be. In all ordinary discussions of the center of gravity, the objects considered are so limited in dimension that the forces of gravitation may be supposed to act in parallel lines; but in treating a section of the earth's area, one-eighth of a circumference in extent, this assumption can no longer be permitted. Here gravity acts along the normals to the surface, which converge, approximately, at the center of the earth.

Again, even supposing that the forces of gravity influencing this spherical shell acted in lines parallel to each other, and to the normal to the surface through their center, the moment of each of these forces would then be the product of its intensity by its perpendicular distance from the center; that is, by the sine of the arc included between its point of application and the center. But, in getting the center of population, it is evident that the leverage to be taken as a factor in obtaining the moment of any group of people is the distance that they would have to travel in order to reach that center. People do not travel along the sine of an arc, however; they follow the arc itself, and in theoretical journeys, as all of the migration of this discussion must be, they take the shortest route, that is, the great circle.

By thus considering that all leverages reaching from the center of population, or the axis passing through the same, to the distant city or state, are measured along the earth's surface, we are relieved from one of the embarrassments which affect the determination of the center of gravity; and by further assuming that these measured arcs are stretched out

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and coerced—as best can be done—into a plane surface, tangent to the earth at the center of population, the various normals, now normal to the same plane, become parallel lines, and the center of population becomes a center of parallel forces.

Thus simplified, it is not a difficult task to determine this center. But there is a flaw in this process. It results from the impossibility of representing a spheroidal surface upon a plane and preserving all areas, proportions and distances in their true values; in other words, the surface of our spheroid is not capable of development. When it is remembered that the leverages which enter as factors into the various moments are distances upon the earth's surface, it will be seen that a true expression of them is necessary for a rigidly accurate determination of the center of population. Such an expression can only be found by a computation of the lengths of the arcs which constitute these lever arms.

Since the center of population is that point about which there is an equilibrium of moments, there must also be equilibrium with respect to any two rectangular axes which may be drawn therethrough. Upon the earth's surface these rectangular axes become two great circles perpendicular to each other. It is obviously most convenient to adopt for this purpose the meridian through the assumed center, and its perpendicular, which is the prime vertical at that point. It would now be necessary, in the method under contemplation, to compute the leverage of every group of population with respect to each of these axes. This leverage is the shortest distance from the group to the line aforesaid; that is, an arc of a great circle perpendicular to the axis. So laborious a process as this, involving so many computations in geodesy and spherical trigonometry, is manifestly impracticable and quite out of the question, and is mentioned here only because of the theoretical interest it may possess.

To return to the graphic and approximate mode, it is possible to construct a map of our country in such a manner, that the leverages taken by direct measurement from the perpendiculars let fall from the local population centers to the assumed axes, will give a national center whose probable error, resulting from the inaccuracy of the method employed, will be less than the other error arising from the crude but inevitable custom of handling the population by communities instead of by individuals. Any greater precision than this is not worth the immensely greater labor that it would cost. It is now the object of this article to propound some way, sufficiently rapid to be practicable, of attaining this degree of exactness.

As has been said, the spherical shell must be considered as a plane surface. But there are numerous ways of doing this. Every style of map projection is a transformation of this kind, and, unfortunately, every one involves some displacement, distortion, or expansion or contraction of areas and distances. We now seek a projection which will incur a minimum amount of error in dimensions and relative positions, and whose conditions will thus be most favorable for the work at hand.

As the leverages are to be the perpendicular distances from the local centers to the great circle axes, it is important that these great circles should appear on the map as straight lines, intersecting at right angles at the assumed center; or, failing in that, that they should approach as nearly as possible to rectilinearity. Cassini's projection is the only one known to the writer in which these two great circles would be projected into right lines; but this method is attended by so many disadvantages—among others the obliteration of our convenient division of a country into square degrees by its reticulation of meridians and parallels—that it may be dismissed from further consideration.

In the polyconic projection, taking the middle meridian through the assumed center and making it one of the axes, it will be projected into a right line, while its co-ordinate axis—the prime vertical—will not depart far from the same auspicious condition; its greatest deviation from rectilinearity within the limits of the United States would not exceed forty miles. This will not produce a curvature that will materially interfere with the process of drawing perpendiculars to it from the local population centers. The principal argument against the use of the polyconic projection in this work is

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that uniformity of scale is not preserved, it being sacrificed in order to retain a natural angle of intersection between meridians and parallels. Thus any two parallels of latitude on the map, instead of being concentric, and therefore equidistant throughout, as they are upon the earth's surface, separate more and more as they leave the middle meridian. With the middle meridian passing through Ohio, a projected degree of latitude in Oregon or Maine is much longer than in Michigan. In this way the population of those remote northwest and northeast regions will be given greater north leverages than they are entitled to, and the resulting tendency will be to draw the national center unduly northward.

The preceding method is given for what it may be worth. It possesses at least the merit of convenience, as the data for the polyconic projection of a map are widespread in this country, and draughtsmen are familiar with their use. Moreover, with all of its faults, it is warranted to give results much more accurate than any hitherto attained.

Finally, we come to the consideration and adoption of Bonne's projection, which is by all odds the best adapted for delineating a portion of the earth's area, so that, having allotted weight to this map according to its density of population, the center of gravity of this plane will most accurately represent the center of population of the spherical surface.

In Bonne's projection, as in the polyconic, the middle meridian becomes a straight line. The central parallel, also as in the polyconic, is projected in the arc of a circle whose radius is equal to the slant height of a cone, tangent to the earth at this parallel, and of whose base this parallel is the circumference. All other parallels are concentric with the middle one, and are drawn at their natural distances apart. All lengths of parallels are also correct. An equality of areas, upon the earth and on the map, is thus preserved, although the shape of those square degrees remote from the middle meridian and parallel becomes distorted, and rhomboidal, their diagonals being unequal, owing to the oblique intersection of meridians and parallels. This fault is of but little importance in the present work, where the principal desideratum is uniformity of scale with regard to the axes, and hence correct relative positions, in which respect no other projection offers equal advantages. Add to this the fact that the projection of the prime vertical through the intersection of middle meridian and parallel scarcely deviates from a straight line, its departure from rectilinearity within our boundary not exceeding ten miles, and the fitness of Bonne's projection for a population map is assured.

Therefore, to find the center of population of the United States, first assume a center from an inspection of the map or from rough preliminary calculations. It is important that the assumed center should approximate in position as closely as possible to the true center, so that the rectangular great circle axes through the former may be considered parallel, for the portion included within the United States, to the corresponding system through the latter, to which the first axes are to be shifted in the final adjustment. Make the assumed center the point of intersection of the middle meridian and parallel of a map projected after Bonne's method, and divided into square degrees. This map need not be drawn in detail. Outlines, boundaries, and the positions of those principal cities which are to be treated separately will suffice. Local centers of population may be taken from any ordinary map and transferred to this.

Draw through the assumed center the projection of its prime vertical, tracing its course by computing the latitudes of its intersections with meridians which it crosses. With this as one axis, and the rectilinear projection of the middle meridian as its co-ordinate, proceed to find the moments, with respect to these axes, of the numerous collections of people into which it may be deemed advisable to divide the country. Under the direction of Mr. Henry Gannett, the very efficient geographer of the Census Bureau, the population of the United States has been grouped by square degrees, and, it is to be hoped, will be published in that form. Such an arrangement will greatly facilitate all studies concerning the geographical distribution of our people, and will be especially useful in finding the center of population. A determination of the center by the use of square degrees and the leading cities will re-

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quire about one thousand moments for each of the two axes. The leverages of these masses will be their perpendicular distances, measured on the map, from the axis in question. There is, to be sure, a slight element of error in this manner of finding the value of an arc of a great circle, but it is so inconsiderable that it will not perceptibly affect the result, and it would be a thankless task to attempt to eliminate it.

After the summation of the moments thus found, and a comparison of the results, east with west, and north with south, the adjustment of the center to its true position is accomplished as described in the early part of this article.

In determining the center of population hitherto it has been customary to accept, for the rectangular axes through the assumed center, the meridian and parallel intersecting at that point; that is, a great circle and a small circle. Leverages of the population masses with regard to the parallel have been measured along their respective meridians, and are therefore arcs of great circles, as they should be; but the leverages about the meridional axis are the arcs of parallel intercepted between the local centers and that axis, and are, in comparison with the proper lever-arms, as the hypothenuse is to the perpendicular.

A moment's contemplation will show that this is equivalent to adopting, for the axes of a plane, a straight line and a curve intersecting at right angles, and then using curved instead of perpendicular lines for the leverages with respect to the rectilinear axis. Of these two erroneous processes, the latter will cause the center a slight displacement in longitude, while the former will seriously affect its position in latitude, throwing it many miles too far southward.

As heretofore determined, all north leverages are deficient and all south leverages are excessive, except those lying along the meridian of the center. The greater the distance of a group of population from this meridian, the greater is the error of its moment. On the Pacific coast, for instance, the parallel of the center of population is more than four hundred miles distant from the prime vertical passing through that point. The leverage of any group of population, by the old method, is erroneous to that extent. As an example, the city of San Francisco is nearly a hundred miles south of the parallel aforesaid, and has been given a south leverage of that amount, when, in reality, it should have a north leverage of more than three hundred miles. In the same manner, all other north and south moments are invalidated by this fault of accepting a small circle instead of a great circle for an axis.

The west leverage of San Francisco is also as much too large as its distance from the meridional axis by arc of parallel is longer than by an arc of great circle. But these excessive leverages in the west are partly compensated for by a corresponding excess in the east, and the resulting error in the longitude of the center is not so great; a mile or two would probably cover it. It is difficult to estimate, from a mere inspection of the map, how great an error of latitude may affect the center of population, as determined by the old method, but the center, thus found, of the population of 1880, falling in northern Kentucky, a few miles west of Covington, its true position is probably about thirty miles farther north and a trifle to the east; that is, in Butler County, Ohio.

It may seem improbable that the center should lie so near our northern boundary, but it should be remembered that our country, in general shape, is the segment of a zone, and if this segment were extended far enough in longitude its center of population would be situated entirely outside of the country, beyond its northern limit.

The difference between the plan herein proposed and the one hitherto followed, in determining the center of population, may be graphically illustrated by a comparison of Bonne's and Flamsteed's projections of a map. The latter is an exact counterpart of the plane surface into which the spherical shell is supposed to be projected in the old method; that is, its parallels occur at their natural intervals, but are straightened out into right lines, all of which are perpendicular to the middle meridian, itself a straight line. The middle parallel is taken as one of the rectangular axes, both of which, upon the map, are rectilinear. Thus this process has a plausible

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appearance, until it is remembered that the distortion of this parallel into a right line necessitates a great curvature in the projection of the corresponding prime vertical, which is the real axis, and a great displacement of areas. Flamsteed's projection, therefore, while it is easily comprehended by the popular mind, which is accustomed to consider our country as a plane surface, across which east and west courses run in straight lines, is really one of the most untrue in existence.

In thus criticising past dealings with this subject, the writer does not flatter himself that he has discovered an unconscious use of faulty methods in the work of the able investigators who have preceded him in the study of this matter. Taken at the best, its treatment must be approximate, and hitherto the newness of the subject, an absence of popular interest in it, the pressure of more important work, and other exigencies of the public service, have combined to preclude any other than the most convenient and least laborious handling of this topic. It may even be doubted if, at the present day, it is advisable to bestow upon it the increase of labor entailed by the project announced in these pages; but in the future, as our methods of work become more and more refined, and especially as our northwest country and the Pacific Coast, remote from the center, become thickly populated, and the error of their influence upon the center is correspondingly increased, it will certainly be found necessary to attempt a closer approximation than has yet been accomplished.

The old plan has an advantage of convenience in the fact that all distances along the meridians and parallels of our country, which are the leverages therein used, are already computed and tabulated in geodetic handbooks. And, although the absolute situation of the center is not accurately given by that method, it shows correctly its relative positions, decade after decade, and its constant westward migration with its fluctuations to the north and south.

Through the enterprise of the Hon. Francis A. Walker, Superintendent of the Census Bureau, the center of population was made an interesting feature of the census reports for 1870, and will, doubtless, find a place in all future discussions of the movement of our restless people. By computations made under his direction, and by independent determinations contributed by Prof. J. E. Hilgard, of the Coast and Geodetic Survey, he was enabled to locate, upon his population charts, the successive positions of the center for each decennial period from the year 1790, when it was east of Baltimore, to 1870, when it had reached a point in Southern Ohio, forty-eight miles from Cincinnati. For the details of its progress the reader is referred to the chapter by General Walker, entitled "The Progress of the Nation," in his valuable Statistical Atlas of the United States, and also to an article by Professor Hilgard, published in *Scribner's Monthly* for June, 1872, under the heading of "The Advance of Population in the United States."

From these authorities it seems that the migration of the center of population, almost uniformly westward, has been at an average rate of fifty miles a decade, five miles a year, or seventy-two feet a day. This, then, is the measure of the progression of that imaginary, but important point, the "hub" of the United States, which is destined to move, with slower and slower pace, until it shall reach, a century hence, the immediate valley of the Mississippi, where it will permanently settle. Though the West grow strong at the expense of its parent, the East, and the one flourishes as the other becomes effete, this shifting of power is no sudden and startling process, as will have been seen. The emigrant's ox-team, the type of all things slow, and by which this transfer of empire has been largely effected, outstrips a thousand fold the center of population in its advance.

It has been judicially decided in the American law courts that a mail agent, or traveling post-office servant, when traveling as such on railroad trains, is not a passenger, and cannot therefore recover damages for injury in case of accident; also, that a passenger riding in a baggage car when there is room in the passenger cars cannot recover in case of injury, if it shall appear that he would not have been injured if he had been in the passenger cars.

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NEW MODE OF COMPENSATING BALANCES.

By CHARLES V. WOERD, Sup't Engineer of Waltham Watch Company.

THE form of compensation hitherto employed in the balances of watches and chronometers can be made perfect only for two critical temperatures, and is imperfect for intermediate or extreme temperatures. Devices called secondary or auxiliary compensation have been applied to remedy this defect in a partial degree. The effect of the temperature is to modify the elastic force of the spring as well as to change its length, and to change the form of the balance; and perfect compensation requires that the time of vibration of the balance shall be constant under all the vicissitudes of temperature to which the instrument may be subjected. This requires that an arrangement of the parts shall be made such that the moment of inertia of the balance shall maintain a constant ratio to the moment of the elastic force of the balance spring. The law of the change of the effective elastic force of the spring is not certainly known; but sufficient is known in regard to it to make it certain that the compensation cannot be made perfect except at two temperatures. The expressions of the variations of these moments in respect to the temperature, give, when graphically represented, two curved lines, and the adjustment can be made only for the two points where these curves intersect.

Fig. 1

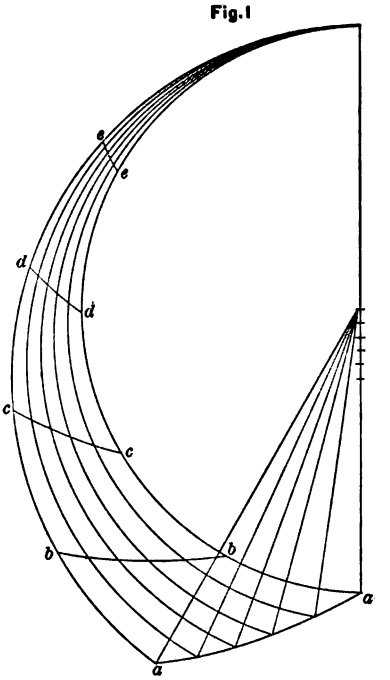
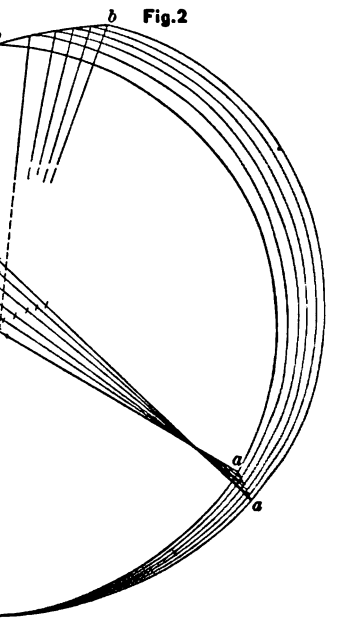


Fig. 2



The device consists in the substitution of an entirely different arrangement of bimetallic laminæ, in such a way that the ratio of the moments of the balance and of the spring shall remain constant during all the temperatures to which the watch or chronometer may be subjected while in use.

First, for the inner lamina steel is employed as usual, but the outer lamina is constructed of a composition of higher expansibility than brass hitherto used

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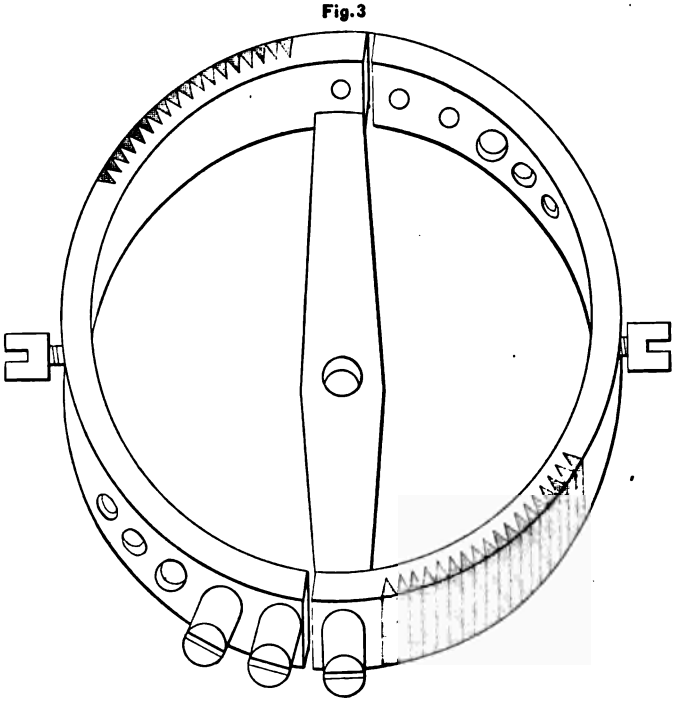
for that purpose. Instead of two parallel connected laminae, only a short arc of the outer composition is employed, and this is connected with the steel in the form of intermeshing teeth fused solidly to the steel. The outer rim is turned down so that the fine edge of the steel teeth separate the composition into a succession of prisms.

By this means the action is different from that of continuous bimetallic laminæ, in that it avoids the difficulties arising from the constrained and irregular action of the laminæ, and provides for that freedom of movement of the compensating weights which is necessary to fulfill the actual requirements of the adjustment for temperature.

Second, by means of this arrangement it is always possible to find the number of teeth in the bimetallic part of the rim which, in connection with the proper compensating weights, will make the motion of these weights correspond with the requirements of the balance spring for tautochronous vibrations at different temperatures. In order to lighten the steel rim and keep the effective weight of the balance as near the extremities of the segments as possible, one or more holes are drilled in this steel rim, and intermediate between the bimetallic part and the compensating weights, so that the desired effect may be produced by a limited arc of the two metals. This provides also for a delicate adjustment of the poise of the balance.

Fig. 1 represents the movement of the compound laminæ under a decrease of temperature in the form of bimetallic compensation hitherto used. The inner

Fig.3



curve represents the rim of the balance at a middle or normal temperature. The outer curves represent its successive positions at diminished temperatures, and the oblique lines *a*, *a*, *b*, *b*, etc., show the motion of the compensating weights placed at different positions of the rim. The curves described by these weights do not in any case change the moment of inertia of the balance in the required ratio and the compensation is therefore imperfect.

Fig. 2 represents the motion of the rim of the balance when constructed in accordance with this device. The inner

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curve shows the normal position at a middle temperature, and the other curves show its motion under successively diminished temperatures. The curved line *aa* shows the path of the extremity of the bimetallic arc, and *bb* shows the curve described by the compensating weights at the outer extremity of the segment. The proper number of teeth in the bimetallic part to correspond with the thickness of the continuous steel rim, to be easily found in the actual adjustment, will give to this curve the form which is required in order that the rate of change of the moment of inertia of the balance shall be always sensibly the same as that of the moment of the elastic force of the balance spring, so that the compensation may be made practically perfect.

The forms and relation of the curves in the two cases will be similar when the temperature is increased from the normal temperature considered.

Fig. 3 represents the balance complete, constructed in accordance with this device. The steel arm of the balance is represented at *a*. The steel portion of the rim is shown by the light portions, and the composition for the outer part of the bimetallic portion of the rim is indicated by the lined parts. The number of teeth depends upon the thickness of the rim, and should include in general about one-sixth part of the circumference. The rim is cut very close to the extremities of the arm of the balance, and the compensating weights are placed near the outer extremities of the segments. The small holes shown intermediate are made in order to keep the resultant action as far as possible from the bimetallic part of the rim.

RECENT ADVANCES IN ELECTRIC LIGHTING.

By W. H. PREECE.

From the "Journal of the Society of Arts."

I AM to describe to you the recent advances that have been made in electric lighting. My position reminds me of a story that is told of Queen Elizabeth, who, on approaching a certain town, was not received on arrival with the usual ringing of bells. On demanding the cause, the chief municipal dignitary informed her Majesty that there were 39 reasons why the bells did not ring, the first of which alone satisfied her Majesty, viz., "there were no bells." So I can almost say "there are no recent advances in electric lighting to chronicle." The advances that have been made have not been so much in electric lighting itself as in the popular favor with which it is regarded. The public is becoming more accustomed to its use, and therefore acquiring more confidence in this mode of producing light.

Electricity and gas are playing a see-saw game. As the electric light goes up, the gas goes down. It reminds one very much of those old Dutch weather houses that used to be common many years ago, but have recently disappeared. When the weather was fine, out came the old woman; when the weather was damp, out came the old man. Electricity made a great splutter in Paris; down went the gas shares. Mr. Sugg and his inventions brought the gas shares up again. An alarming message is received from New York; down goes the gas again. The friends of gas have scarcely had time to recover themselves when the City of London, with great wisdom and foresight, votes a very large sum of money to be expended in carrying out a gigantic electric lighting experiment, and this has brought the old man out once more.

The result of trials during the last year or two have been to give experience in the vagaries and capriciousness of this light. Its defects have become better known. We have been taken out of the experimental, and have been brought within reach of the practical stage. Now details are being elaborated, mechanical appliances supplied, and much useful knowledge is being acquired by those who have had the enterprise and

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the farsightedness to launch their money in this new venture.

The progress of electric lighting can be looked at from three points of view—scientific, commercial and practical.

My task has been rendered very light, by the admirable series of Cantor lectures that have recently been delivered in this room by Professor Adams. He has thus enabled me to shake myself away from scientific detail, and to deal more with commercial and practical generalities. I will, therefore, glance rapidly at the commercial and practical developments of the principal portions of the system which together make up electric lighting. Let us first take the motor, the power by which scientific skill has enabled us to convert a source of energy into another form. The problem we have to solve is how to extract the greatest amount of light out of a lump of coal. Of our agents to help us, the poor old engine is much neglected. When I think of the work done by that willing slave, the engine, I am reminded of the story of the organist and the organ blower. The blower one Sunday said to the organist: "How magnificently we played Handel's . . . to-day!" "*We* played," replied the organist, "you impertinent fellow, what do you mean by "we played?" The blower said not a word, but on the next occasion when the organist wished to play, the blower declined to exert himself, and on being remonstrated with, he said: Do we play, or do we not play?" The organist said: "Yes, we do play," and instantly the organ pealed forth. So with the engine, where should we be without the engine? The reason why the electric light has, within the last few years, come so much to the front, is because electricity has been produced by the direct conversion of mechanical energy into electricity, instead of by means of batteries, which were the only sources known years ago. Now, thanks to the steam engine, we are able to fulfill all those requirements that enable us to produce cheap electricity. Those requirements are high velocity, great steadiness, and uniform pressure; and those are the points which are gradually being acquired in the steam engine produced from our workshops. The velocity of 800 revolutions per minute, sometimes even of double that rate, is an enormous velocity to maintain, but it is essential for cheap electricity. Eight hundred revolutions a minute need not frighten us, for we care not what the speed of rotation is in the wheels of our express trains. No one troubles his head much about the tremendous velocity acquired by a carriage that runs continuously for 24 hours or more, and, therefore, we need not be alarmed at the velocity acquired by our stationary engines working electro-dynamo machines. It is not too much to say that what little success belongs to the electric light on the Thames Embankment, is due to the engine planted beneath Charing-cross bridge, by Messrs. Ransome, Sims and Head.

Nor should I say that the success of the electric light in the British Museum is due any the less to the Wallis and Stevens' engine than to the magnificent apparatus put up by Siemens Brothers. It would be invidious to name the different engineers who have brought out special engines for this purpose, for their name is legion. Marshalls, Brotherhoods, Robey, and others have worked hard in this field, and have succeeded in producing engines which, by automatic governors and by other means, provide all the requirements that the electric light demands. It would be difficult to over estimate the good that has been done in this direction by the competitive trials instituted by the Royal Agricultural Society. The small engines that distinguish English engineers, are almost entirely due to the interest excited by these annual trials. Instead of one-horse power requiring 7 lbs. and 8 lbs. of coal to produce it, it is common now to find engineers producing one-horse power by even 3 lbs. of coal, and in some engines 2 lbs. per horse-power has even been attained. It is strange that nothing has been done to supersede steam as a generator of power. It is well known that the specific heat of water is higher than that of every known substance, and is not beyond the reach of theory to assert that there are other liquids whose evaporation should produce the same power with a very much less expenditure of fuel. There is a vast field for invention in this direction. The gas engine is a very economical source of energy, and has been very successfully applied to

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electric lighting in many places. At the Docks in Newport, South Wales, a gas engine has been in use for nearly two years with great success; and it is worthy of note that if 100 cubic feet of gas per hour gives a candle power of 300, that same gas applied to an engine would give, in electricity, a candle power more than 11 times greater, namely, 3,750 candles. Here is a sphere to maintain gas dividends.

Water is another convenient source of energy, when you can find it available. Sir William Armstrong, at Craigside, near Newcastle, has utilized a brook for this purpose, and, by the aid of a turbine, produces a force giving six-horse power; in fact, he says: "The brook lights his house."

I am not aware yet of air having been utilized for this purpose, except when heated in the caloric engine in use at the Lizard Lighthouse, which is found to be economical, useful, and very suitable for such isolated places where it is difficult to provide water. It is, therefore, clear that some advances have been made in the economy and the adaptability of motors for electro-dynamo machines to produce the electric light.

With regard to the generator of electricity, the instrument by which the energy of steam or water is converted into electricity, after Professor Adams not much remains for me to say. There are several excellent machines. The difference between each is very much the difference between twedledum and twedledee. Each is specially adapted for its particular work, either by a variation in velocity, or by a variation in the way in which the wire is wound, so as to produce a variation in the current produced to suit the particular light required. The efficiency of any machine is the amount of energy which is converted into current, and it has been shown that both in the Siemens and the Gramme machines nearly 90 per cent. of the power is converted into useful current. It is easily demonstrable that there is economy in the use of small machines, and it is difficult to understand the reasons that induce some people to speak of the value of the enormous machines that have been constructed in America. In fact, in this department, a great deal of time and energy is being wasted in trying to gild refined gold. Changes are being introduced for the mere sake of change. The improvements that have been made have been improvements in detail only. Broadly speaking, there are two classes of machines, those which produce continuous currents, and those which produce alternate currents. Very little advance has been made in the efficiency of the earliest forms in every case; and I learn from Mr. Douglass, of the Trinity-house, that the original Holmes magneto-electric is still in use, and doing good work, at the Souter Point and South Foreland lighthouses, and that a De Meritens magneto-electric alternating current machine, of similar type, has been under trial at the Lizard for the last four months, and that he is greatly pleased with its efficiency and reliability. The De Meritens machine is an excellent one, and one of which we shall hear more. The trials made for the Trinity-house showed that more efficiency was obtained by joining up small machines in multiple arc, than either by the use of a larger machine, or by the same machines joined up in series. This is a point that has escaped the notice of recent experimenters in this direction, and it is well worth their serious consideration.

The battery has been discarded as a generator of electricity from its want of economy, but there are hopes that secondary batteries will be introduced for the purpose of storing up this force. No advance has yet been made, however, towards the practical attainment of this desire. Many attempts have also been made to utilize the thermopile, but in all cases it has been shown that the electromotive force produced is too low. The thermopile has this advantage, that it is wonderfully durable. I saw, last week, one which has been in use for four years uninterruptedly, night and day, without intermission, and it still gives out electricity with all its pristine vigor.

The conductor is the broad road along which electricity flows to produce light at a given point. In all cases, from its superior conductivity, copper has been selected. Sometimes this copper wire has been carried overhead and sometimes underground. Where it can be carried overhead, it has the advantage over underground that, as the heat radiates into the open air, the wire itself becomes

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cooler and conveys more electricity. In practice, the purest copper is used, and wire of the largest dimensions consonant with economy, for the resistance or obstruction to the flow of electricity must be maintained as low as possible, to prevent waste of energy. In the different experiments which have been carried out in London, one feature noticeable to me has been in some cases the utter ignoring of the experience gained in telegraphy. The way in which wires are suspended, and hung, and moved about, is to the mind of the telegraphist simply disheartening and appalling. On the Metropolitan Railway the wires were so decayed, and rotten, and ill-used, that they had to be removed, and the lighting of the Victoria station of the underground railway was abandoned. The currents used for electric lighting are more than three thousand times greater than those used for telegraphs. We have great difficulty in maintaining the small currents used in telegraphy along their proper course, and the small defects that have, in thirty years' experience, made themselves evident to us, are simply magnified in their hurtful effects 3,000 times when applied to electric lighting currents.

Electric currents have also a peculiar and serious influence on wires passing in their neighborhood. It is an influence called induction, and one that produces serious disturbing effects. In fact, so powerful are these disturbing effects that very great fears are entertained that it will be impossible to maintain electric light and telegraph circuits close together. Recently, at Holyhead, telegraph communication was completely broken down along a wire that ran side by side with the wires conveying an electric light, during the time the current flowed to produce the light. We of the post office are watching carefully for any interference by electric light currents in this respect.

Why do electric currents produce light? Light and heat are mere terms given to what are really similar operations. Certain undulations impinge on the retina of the eye, and give that sensation which we call light. They fall on our skin, and produce the sensation of warmth. They are incident on certain salts of silver, and produce photographic pictures. The flow of electricity means the generation of heat. The production of light is the accompaniment of intense heat. In fact, the brighter the light, the intenser the heat. The art of producing brilliant light is the art of producing high temperature. There is no greater illusion extant than that the electric light is a cold light. The electric arc is the greatest source of heat known. Our worthy chairman has shown us how it can reduce to liquid the most refractory metals; and at his country house, near Tunbridge Wells, he has kept a stove house at 70° by its aid. Professor Dewar measured the heat radiated by the light he used, and found it sufficient to produce three-horse power per minute; hence electric currents produce light because they produce intense heat.

Now, this heat can be produced either by causing the electricity to fly across an air space, in which case we have light by the arc, or by causing it to flow through a small wire, or a carbon filament, which offers obstruction to the flow, and produces light by incandescence.

We have burning to-night several specimens of each kind. The forms of arc lamps are very numerous. In every case carbon rods are opposed to each other, and they are disintegrated and consumed in the fierce blast to which they are subjected. The lower pole—the negative—acquires a temperature of 3,150° C., it is broken up and fired with a fierce bombardment of white hot molecules across the air against the upper pole—the positive—which is beaten up by incessant impacts into a higher temperature of 3,900° C., the arc itself being 4,800° C. On account of the irregularity in the character, and, therefore, the consumption of carbon, and the variation in the strength of the current, various ingenious appliances have been adopted to obtain steadiness and uniformity in action. Mechanism, clockwork, electro-magnetism, gravity, and all kinds of contrivances have been called in; in fact, of arc lamps, their name is legion.

A remarkable attempt was made by Jablochkoff to dispense with mechanism altogether in his candle, but though many thousands of them are in use, it is doubtful whether the candle system will be permanent, for it is expensive and

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wasteful. M. Jamin has recently taken a step in advance in this line, and the trial of his lamp is being eagerly watched.

We have not yet obtained perfection in the arc lamp. We want brilliance, combined with absolute steadiness, and the durability of a winter's night. Great steps have, however, been made in simplification of parts and smoothness of action; but we lack silence and steadiness.

Many of the defects of the arc light are compensated for in that of incandescence. Here we have something that is beautifully soft, absolutely noiseless, perfectly steady, a light that brightens up nature in all her true colors and purity. I shall not readily forget a dinner party given by Mr. Spottiswoode, the President of the Royal Society, a short time ago, when his room was illuminated by Mr. Swan's lamps. It was not only fascinating, but fairylike and lovely. One felt in a dream. We have had a sample of it here, and the beauty of the light grows on you. The incandescent light is, however, at present, an expensive luxury. It requires a considable expenditure of power. For instance, Sir W. Armstrong finds that six-horse power supplies 37 lights, giving altogether 925 candles. Six-horse power in arc lights would give over six thousand candles. However, we must not grumble. Rapid progress is being made in this field. Maxim, Edison, &c., in America; Swan, Lane.Fox and others, in England, are working hard, while Gordon and Joel are working in an intermediate field, where a prospect appears of a happy compromise being effected between the arc and incandescence. We have, to-night, an illustration of the burning of the Joel lamp—a modification of that introduced by Mr. Werdermann.

A good many wild statements are made about the light-giving power of these different lamps. A standard sperm candle may be a very good unit to measure gas by, but it is a very poor standard for the electric light. Of course the advocates of the electric light overestimate their case. It would not be human nature if they did not; but their divergences are wonderful. Thus, the Glasgow committee makes one horse-power produce 600 candles; the Trinity House, 1,254; a Paris commission, 2,500; a certain Anglo-American Light Company, an unknown quantity!

We have two natural standards to refer to, sunlight and moonlight. We have various physical forces to appeal to for measurement, photographic records, the production of heat, the estimation of shadows, &c., but the standard of the future remains an *ignis fatuus*. To estimate the value of a light, you must not look at it; you must turn your back to it; you must try and read small print by it, and then you will find what a godsend it would be to find some means by which we could estimate the illumination of a square foot or a square yard. We want not only a new standard of light, but we want a new system of photometry. Efforts have been made to estimate the intensity of the light radiated by the size of the craters found on the carbon rods; but this mode of measurement is empirical and illusory, for it varies with the character of the carbons and the currents used.

A word about that "philosopher's stone," that *elixir vitæ*, the subdivision of the electric light. What does it mean? It means that certain gentlemen hope, from one central spot, to distribute electricity, as they do gas and water, throughout our houses, so as to furnish great cities with cheap, pure and abundant light. "'Tis a consummation devoutly to be wished." Now, I am one of those who do not believe in the word "impossible," but I say, that with our present knowledge, this problem is insoluble. There are those who don't say so, but who think I am an obstructive lunatic. But what are the facts? Numbers, thoughts, words, can be manipulated anyhow—hence Whig and Tory, High Church and Low Church, *et hoc genus omne*, but facts are inexorable. Sir William Armstrong can only keep 37 lights going; Lane Fox could only show 12 lights; Professor Adams could only produce from the most powerful dynamo-machine, by calculation, 140 lamps. Where is the subdivision? The advocates of subdivision assume an exhaustible source of electricity. Their opponents reply that there is but a very limited source of energy in every dynamo-machine. Subdivision means loss of

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power, waste of energy, and useless expenditure. We are not all Sir William Armstrongs, who can say of his brook, "I can afford to waste that which costs me nothing." One ardent disciple of subdivision says: "There is practically no loss in dividing the electric light produced by this means (by incandescence)." Now, is the production of 925 candles when you ought to have 6,000, no loss? Is the production of 3,600 candles on the Thames embankment, where you ought to have 25,000, no loss? Our dynamo-machines have their limit, and no power on earth, either of subdivision or of multiplication, can make the machine do more than a given amount of work. It may be that in course of time, and, probably, very soon, too, more powerful machines and lamps of lower resistance, may enable us to light up a greater number on one circuit, but this is not subdivision, it is multiplication. I anticipate more advantages from the transmission of power, and I look forward to the day when I shall have in my own house a small and simple dynamo-machine, working my own lamps, and no one else's. I have not the slightest ambition to be dependent on electric currents generated miles away, and liable to all the interruptions to which I, as a telegraph engineer, have had long and painful experience.

Now, having got our light, the next question is, how can we utilize it? This question, as far as external illumination is concerned, is about to be solved for us in a very interesting way by the city authorities. We have, first, the centralized system of Dr. Siemens, where one machine works one powerful light, raised like a small moon upon the top of a high mast; and we have, secondly, the distributed system of the Brush Company, who utilize the existing street lamp posts, one machine working many lights. I have no doubt myself, from my own observations, that for symmetrical spaces, large areas, such as docks, parades, squares, &c., the former is the best; but for long and narrow streets and thoroughfares, the latter will prove superior.

The same arguments apply for internal illumination. Nothing can be more perfect than the centralized system at the British Museum, while the distributed system would alone meet the case of such a place as the Waterloo railway station. For the former we want height and space; for the latter length and lowness. In fact, the longer and lower the place to be illuminated, the less is the intensity of the light required; and when we come to long rooms and passages, we possess all we require in the small incandescent lamps. It is not difficult to show that such conditions may arise, even in external illumination, that a few small lamps, well distributed, will illuminate better than one or two powerful ones.

An eventful feature in practical lighting is the proper scattering or diffusion of light, by shades, screens, and reflecting surfaces. There is an archway at Waterloo station that is wonderfully lighted, owing to the white glazed tiles on its sides, forming such admirably reflecting surfaces. We want to emulate the diffusion of daylight. It is marvelous how whitewashed surfaces do this. Well selected globes act as though they were self-luminous — they scatter light and prevent shadows.

The reason why daylight is so diffused, and the light searches out the inmost corner of our cupboards and our drawers, is simply that practically the whole sky becomes the source of illumination, light radiating from each point. One interesting question that will be solved by the great experiment commencing tomorrow in the city, will be the relative efficiency of different lights in penetrating fogs. It is a point open to the observation of every one of us, that the electric light upon the Thames embankment exhibits no more power in penetrating fogs than gaslight. The reason of this is extremely simple. Light, as I have previously explained, is due to the undulation of matter. There are waves and waves; some like the mighty ocean swell, tossing the "Great Eastern" like a cork in a basin; others are reflected from the side of the cork, as the billows of a storm are tossed back by a solid pier. The color of the sky is due to the reflection of the tiny blue waves, by excessively minute material particles floating about. The red sky at night is due to the unimpeded transmission of the larger red waves, the smaller ones being checked; hence the dull red of the

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round sun in a mist, and the destruction of the smaller rays of the electric light, which lend it that bright and brilliant violet tint in clear weather. For the same reason that the penetration of the electric light is no greater than gas, its illuminating power in its immediate neighborhood is more. For these small rays which had been checked by material particles from penetration are reflected back to the immediate neighborhood of the light. There is a great difference between the quantity and the intensity of light. There may be a light of very low intensity, but yet of such large quantity as to penetrate to a considerable distance. A ship on fire at sea, for instance, is seen to an enormous distance; and it must not be forgotten that the law of squares, by which the relative intensity of light is determined, is true only for points; it is not true for surfaces. A large flame of gas, though its intensity is so much less, may be as luminant as a point of electric light. Beacon fires, though of very low intensity, are visible very far. In fact, if we increase the luminous area as we recede from it in proper ratio, we shall maintain the same amount of illumination; hence the great failure of photometric measurements to which I have alluded. A photometer measures the intensity of light, not its quantity.

It is important to acquire some experience from the actual users of the electric light, and to know what amount of business has already been done. For instance, there are nearly 300 Gramme machines in use in England generating light. There are many more Siemens', while the Brush people have already installed many machines and lights.

The Trinity-house, who have applied the electric light to lighthouse purposes, have at present confined its use to Souter Point, South Foreland, and the Lizard. They find that the expense involved in the installation of the light is very considerable, and it cannot be adopted without very strong and powerful reasons. Perhaps the greatest extension in the use of the light has been for naval purposes. Nearly all our present ironclads are supplied with the electric light. The last addition to this list, the "Inflexible," will have no less than two Brush machines, each producing sixteen lights. These machines will be arranged to work together or separately. There will be lamps in the citadel, in the engine and boiler-rooms, in the steering platform, below the torpedo department, in the magazine and shell-rooms; they will be used for buoy lights and masthead lights, and probably, as there will be plenty of accommodation on board for the production of electricity, the cabins will be lighted with some incandescent lamps. The "Minotaur," again, is fitted with sixteen Brush lamps; and, in fact, for torpedo purposes, the light is not only useful, but absolutely essential. Last year I had the pleasure of spending some time in the Mediterranean on board a ship laying a submarine cable between Marseilles and Algiers. Our operations were carried on by night as comfortably as by day, by the aid of the electric light.

Libraries, again, have become a useful field. Reading by gaslight is irksome; reading by the electric light is simply delightful. The Picton Gallery at Liverpool has been so lit for a long time, and the British Museum is now permanently illuminated by five arc lights, which fully answer the purpose. This has enabled the authorities to keep the reading room open daily through the winter till seven o'clock, and only on one day (and that within a short time of the hour of closing) have the lamps failed, the failure being due to a want of proper fuel for the engines. At South Kensington 32 Brush lights are used with great success, and afford every satisfaction, not only as a luminant, but in an economical sense.

Railway stations are gradually adopting the lights. The Liverpool-street Station of the Great Eastern, the Paddington Station of the Great Western, the Waterloo-bridge Station of the London and South Western, the Charing-cross Station of the South Eastern, the Bricklayer's Arms (Goods) Station of the South Eastern, are being practically and effectively lit, and the St. Enoch's and Queen-street Stations at Glasgow, as well as the Victoria Station at Manchester, are equally successfully being lit.

Again, we find seaside resorts availing themselves of it for the illumination of their parades. Blackpool, for instance,

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has, with great enterprise, lit up the whole of its parade and piers with great success.

The new Albert Docks on the Thames, the Alexandra Dock at Newport, the Mersey Docks at Liverpool, are all spreading the use of this light with considerable speed. I was surprised last year to find the Belle Vue Gardens at Manchester (a pleasure resort that reminded me very much of the old Surrey Gardens we used to have in London) where, without any expert assistance, the active managers, the Brothers Jennison, had rigged up several lights themselves, and had experienced neither trouble nor difficulty in the matter.

It would be impossible to make any summary of the numerous works, mills, dye works, &c., that have been supplied with lights worked successfully. The Iron works at Barrow, for instance, have very extensively employed it; while the *Times* office was probably the first place in London to inaugurate the introduction of the electric light for such purposes. Shops and warehouses in all parts of the country are now being lit up—Whiteley's, Shoolbred's, Nicholl's, Regent street, Crocker's warehouses in Friday street, and many other places, and now we find the city inaugurating the illumination of their streets and open spaces. I never pass that wretched excrescence that indicates the site of old Temple Bar, without wishing that the heraldic beast that surmounts it were removed, and supplanted by a handsome bronze pillar 30 or 40 feet high carrying a miniature sun. It would not only make the memorial more ornamental, but it would make it useful as well.

One of the most useful purposes to which the light has been applied, is that of photography. Not only are pictures taken by its aid in the wretched fogs of winter, that quite destroy the actinic power of sun rays, but it is used to a very large extent in carrying out what is known as the Woodbury process. The electric light is not so powerful as sunlight, *i. e.*, it does not operate with the same rapidity. Electric light takes, in fact, three times as long to print gelatine reliefs for the Woodbury process, as the sun; but Messrs. Lock & Whitfield assure me that they hardly know what they should have done during the past sunless winter without its aid. Whether the exposure is for one hour in the sun, or three hours in the electric light, is a matter of no consequence, if the quality of the results are similar; the sun, however, has an advantage, due, doubtless, to the greater quantity of light that it emits.

Perhaps, however, the most interesting appliance from a scientific rather than a commercial point of view, is the application, by our worthy chairman, of this light to horticultural purposes. He has found that it fulfills all the requirements for the growth of plants and ripening of fruits; and he has at his country seat, near Tunbridge Wells, carried on a very large series of experiments, that have created quite a sensation in the scientific world.

Notwithstanding these great advances in its use, it must not be forgotten that the electric light has its defects and its disadvantages. All is not gold that glitters. The intense shadows that it emits are troublesome. The unsteadiness of the light is at times wearisome. The hissing that impurities in the carbon and irregularities in the current produce is tantalizing, and the light has an unfortunate habit of misbehaving itself when it is most wanted. Moreover, the problem of durability remains yet to be solved. Many have tried it and abandoned it. In some cases its economy is unquestionable; but there are places where careful persons have shown that gas, as regards economy, surpasses it. It is questionable whether, in some cases, the electric light does not affect the eye. The experience, however, of the readers of the British Museum, is entirely in its favor. Nevertheless, I have myself suffered much from the light; true it was in experimentation, and the same thing might have happened with any intense light; but rumors do exist that eyes have been affected, and probably sufficient time has not yet elapsed to solve this question. The arc light produces, also, nitrous acid and other deleterious gases, as is shown in the condition of the lamps. The incandescent lamp, is, however, free from this trouble. The powerful currents that it requires cannot be carried over buildings and rooms without incurring danger from fire and to life. It has been proposed to utilize

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the electric light in coal mines, but, to my mind, one might as well lay a train of gunpowder along a mine gallery, if it be at all a dangerous one, as a wire conveying such powerful currents of electricity as a light needs, unless that wire be most carefully protected.

The disturbance due to induction I have already alluded to. Nevertheless, in spite of all these defects, the light has great and manifold advantages. The brilliancy of a well-lit room is simply enchanting. The purity of the light for the transaction of business, the selection of colors, and the ordinary daily avocations of life, is simply superb. The cleanliness of the light is one of its great merits. It emits no smoke; but probably its greatest advantage is to be found in the influence it exerts on health. We all know that the air is vitiated to a certain extent, by the mixture of carbonic acid with it, and it has been well shown that to be consistent with health there should be not more than six volumes of carbonic acid in ten thousand volumes of air. When the proportion reaches ten volumes to ten thousand, the action of the heart is affected. When this proportion runs up to from fifteen to thirty volumes in ten thousand, headaches occur, and in higher proportions, rheumatism and bronchitis are the consequences. Now, five thousand cubic feet of fresh air per hour per gas burner, consuming three feet per hour, are required to maintain your health; in fact, in our great galleries at the General Post-office, we require two to three million feet of fresh air per hour to provide a healthy atmosphere. The electric light sweeps away all the necessity for this ventilation. It does not vitiate the air. We have found at Glasgow, where we have applied the electric light, that all these causes of trouble have ceased. Health has been engendered, more work has been got out of men, and, in point of fact, the experience of others shows that the electric light will pay for itself even in the increased work that can be obtained out of labor in consequence of its use. Not only is the health of the subject improved, but men are able to do more work in a given time from the influence of this pure light than from the impure light of gas. We still want brilliancy combined with steadiness and durability. The advances made have not been so much in this direction, as in the improvement of details, and in a greater knowledge of electrical measurements and of the relations that exist between electricity, heat, and light. Electricity as a substitute for gas is not a delusion; it is practicable. It supplies a real want; but for domestic purposes it is at present a luxury, and an expensive one. Predictions as to its grand future have not yet been fulfilled. The public have shown themselves remarkably sensitive to its influence on gas. Nevertheless, it has a bright future before it, and, though the poet might have said:

> "It was a phantom of delight,
> When first it beamed upon my sight;
> A lovely apparition sent
> To be a moment's ornament."

if he had lived in the present day, he would have considerably added to the period in which he estimated the electric light to be an ornament.

ILLUSORY SANITATION.

From "The Building News."

SINCE the institution of local and other Boards charged with the duty of protecting us from the dangers consequent on an improved system of sewerage, ills before unthought of have unpleasantly developed themselves, creating dismay instead of hoped-for comfort and contentment. In the gradual and unavoidable transfer of our personal control of the evils of the house to those endowed with popular as well as legal authority, we lost our individuality, and while contributing to the costs of such machinery became mere helpless units in the force by which it is impelled and governed. Ever since drains and their controlment budded into a science, many a theorist has had ample opportunity of airing his opinions, but in the course of the numerous tentative blunderings, much evil and

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discomfort has been inflicted. To add to what in itself was trying enough, *progress* developed new types of disease hitherto unknown, and the disturbed and conflicting views of our medical authorities added substantially to the dangers of the situation. Hence, like in other matters of a domestic character, an unsettled feeling of distrust has arisen, leading the afflicted—we might even say the oppressed—to grasp at any seeming chance of relief from the uncomfortable and dangerous character of their unsanitary surroundings. Modern unsanitaries, when dissociated from the complex and bewildering phrases which engineering and medical scientists have surrounded it, is a very simple question indeed, for it only really means that the dwelling and its inhabitants have become endangered by a neglect of the most ordinary health-preserving precautions. Whether these dangers are self-sought or vicariously inflicted, does not very materially affect the question, for their existence, under any circumstances, necessitates the most serious attention to their remedy or removal. We may take it, however, that much discord and disagreement prevails amongst those professing to have special knowledge of what is now generally accepted as sanitary science and its complex teachings.

These considerations readily occur to us at the present time from the recent organization of a sanitary insurance society, launched under doubtless creditable auspices, and framed on the model of a similar institution, believed to be doing good and honest service in the metropolis of Scotland. All things must have a beginning, and it is a healthful sign of progress in any direction, when it is founded on a basis practicable and trustworthy in character. Such, we may fairly assume, the parent Sanitary Insurance Society of Edinburgh to be; but, before accepting its teachings or implicitly pinning our faith to its guidance for dealing with a great city like London, we need not be blamed for examining the relative surroundings of the two cities, and considering whether what is good for Edinburgh is equally good for the Metropolis.

Edinburgh is favorably circumstanced as to site which, from a geological point of view, is unexceptionable in facilitating, by the peculiarly favorable character of the rock on which it is built, a ready deliverance of its rainfall and sewage to the conveniently near sea outlet at Portobello. The solid and substantial character of the buildings, and wide and well-conditioned streets of the Modern Athens, are also good and useful factors in securing a tolerably fair state of sanitary comfort. We refer generally to the newer portions of the city, for the Canongate and other similarly circumstanced ancient localities are not by any means perfect in their sanitary surroundings. The city of Edinburgh also, has another and special advantage from its having been the first large community which derived any benefit from the utilization of its sewage, as the long continued fertility of a portion of the Portobello sands testify.

A city so circumstanced and occupied by a comparatively limited high-class population, offers peculiar facilities for the successful treatment of its sewage, due, primarily, to the precipitous character of its site securing a high velocity for its passage to a good and contiguous sea outfall. There are few, if any cities, which command similar advantages, and under intelligent control, sewer gas, as understood in London, need not have any existence in Edinburgh at all. Constructive science generally is in a much better condition, the quality and character of the masonry being better than work for similar purposes in London; for, in the northern city, the "jerry builder" has not yet, nor is he likely to obtain a footing equal in importance to that which he commands in London.

We have thus glanced at the conditions which, by their exceptionally favorable influence on the sanitary state of Edinburgh, and which are being offered as the model, whereby a protection society is to be established for the well-being of the inhabitants of London. Under any circumstances, the difference in extent between the two cities would interpose difficulties in the way of establishing sound and healthy sanitary control and government, let alone the almost insuperable obstacles, the inheritance of governmental supineness and constructive defects. Like unto many other great

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cities of ancient as well as modern times, London is placed upon the banks of a tidal river which, until very recent times, received all its drainage, and sometimes worse, of whatever kind which its inhabitants could not otherwise dispose of. It was not until the abandonment of cesspools and the introduction of larger supplies and use of water that any evil effects were recognized in the use of the Thames as the main scavenger, to whose care was entrusted the waste of London's citizens. When, however, increasing population, and a better appreciation of what may be termed "personal cleanliness" developed to an alarming extent, the river was no longer competent to accept its ancient office without rendering its waters so impure as to create a nuisance which, during certain seasons, almost prohibited its use for pleasure purposes. The malodorous stream, therefore, in all its nastiness on one hand, and the congestion of inland sewage on the other, ultimately resulted in the organization of a powerful body invested with popular authority to undertake the government and control of the main or arterial drainage of London. The area apportioned for the exercise of the Metropolitan Board of Works' rights and authority was limited and prescribed in character, embracing, however, all the parishes proper of the city and suburbs. The physical conditions, however, of the space to be dealt with, were much more unfavorable than those at Edinburgh, neither was the authority so concentrated or effective in its capacity of control. The interception of the drainage of all kinds, was the first condition on which the Board purposed to base their ultimate operations, and accordingly the main sewers were designed to receive and convey to outfalls the whole filth of London and its affiliated parishes. The natural fall of the river Thames in its circuitous course was not very considerable, and as the selected points of outfall were on its banks, any improved gradients of the drains were only possible by reduced length and depressed reservoirs of discharge. The conditions, therefore, controlling the scheme of London drainage are very different, and much more onerous than those existing at Edinburgh, or, indeed, anywhere else in this country. Simple collection and controlment of the accumulated sewage produced from a population of something like 4,000,000 of people, is not, by any means, an easy task, but to provide for its removal or extinguishment is even more difficult. We shall endeavor to describe the machinery by which this task is accomplished.

Tidal influences prevent the free and continuous discharge of the accumulated sewage, and it is therefore desirable only to pump out the contents of the north and south reservoirs at flood tide, or practically twice during every twenty-four hours. The obvious reason for this arrangement is that, theoretically at least, the receding tide conveys the sewage and its associated belongings to distant points which are not supposed to be prejudiced by its deposit, for, according to all natural laws, its total extinguishment is impossible.

Such, then, under normal conditions, is the position of the London main drainage, as now controlled, and to the government of which all other subsidiary drainage is amenable or subordinate. The householder, however desirous he may be of rendering his home proof against the insidious influence of sewer gas, cannot control the insuperable defects inherent in the very inception, execution, and government of the main drain proper itself. He is bound to connect his house, and to pour into the main channel all and every iota of excreta, &c., produced by him and his surroundings into a noisome stream, which already contains, according to the position in which it is emptied, the outpourings of hospitals and divers populations. It is this kind of unavoidable bondage which creates one of the most dangerous difficulties of the sewerage system, for it complicates and intensifies the dangers of the ordinary householder. To clear his house of what, under the modern system of cleansing is regarded as a dangerous common nuisance, he becomes intimately associated with the almost illimitable, and certainly indefinable accumulated refuse of, it may be, millions of his fellow subjects, who, in the universal thraldom of main drainage slavery are helplessly compelled to submit to the lot apportioned them by the controlling authorities. The cleansing of the river Thames by the interception of the Lon-

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don sewage, not only overcame the crying evil of a polluted stream, but it promised comfort to the luxurious inhabitants of a great city, who disregarded the evils likely to follow from such a system when it apparently secured present immunity from the dangers and annoyances of a complex system of cesspools and imperfect drains.

The new dispensation, however, in its complicated surroundings begets evils hitherto unknown, and it is from such dangers that the modern sanitary engineer and scientist promises relief and safety. The main sewer traverses in its tortuous course all sorts of conditions of localities and neighborhoods, and becomes charged with the most heterogeneous contributions from pure as well as polluted sources. Under such circumstances, therefore, the huge and, in constructive sense, substantial sewer conduit becomes a retort for the production of gaseous products, which, from uncontrollable natural laws ascend, finding vent in the weak points of the concomitant subsidiary drains, thus insidiously entering the dwelling, thus engendering disease, and inducing death. From the extreme west to the distant east of the huge aggregation of streets and dwellings of London, and its affiliated suburbs, the slow wending stream of pollution drags its slow course along, receiving from various tidal and other influences, checks to its onward progress towards the point of its ultimate river discharge. Conserved for a brief and naturally defined space of time in the huge reservoirs, it is emptied by mechanical agency on the full tide, which theoretically is supposed to float it seawards, thus securing its removal beyond further baneful influences. This question of removal is of great and paramount importance, which, in the future, will receive some sensible solution, for at present there is much diversity of opinion as to the efficacy of existing means of sewerage disposal. A but recent alarm in the Firth of Clyde, on the banks of one of its numerous and beautiful lochs, seems to show that sewage matter, however carefully dealt with is the source of ultimate danger at the seat of its disposal. · The dredged mud from the malodorous Clyde, into which Glasgow empties its sewage and other abominations, is by means of hopper barges deposited in a deep loch upwards of 25 miles distant from that city. Careful medical examination, influenced by the appearance of new types of disease, proves that they are engendered by the deposit of Glasgow sewage mud, which gradually, even from the depths of its deposition, forms, on the shores of a beautiful loch, posonous matter, which converts one of the healthiest seaside resorts into a pestilential fever center.

London, in like manner, although, by somewhat different means, is freed from its filth; but unlike Glasgow, its population suffers during the process of collection and storage from the poisonous sewer gases which its accumulation unavoidably occasions.

The difficulty, therefore, in contending with sanitary improvements in London is much greater than any other city, because the length and capacity of its main drains create and store up poisonous matter, difficult of controlment, or even elimination. Under certain conditions, indeed, such as those created by heavy rainfalls and floods, an hermetically-sealed house-drain connections would be almost incompetent to withstand or resist the pressure of the pent-up gases of many miles of main drain. There is no present possibility of increasing the velocity of these sluggishly-driven sewage streams, and therefore the sanitary expert, in setting about his task of remedy, must first deal with an evil over which he can exercise no appreciable control. He must fight the demon of disease by remedial rather than by preventive means, and the Herculean task of effectively rendering a sewage-connected London dwelling proof against the entrance of gases is one of difficult performance. Even if the surroundings of the case were in themselves simple and easy, the perfect isolation of a house from its associated sewer, if not practically impossible, is one of more than ordinary difficulty.

Examine the character and quality of the subsidiary sewers of London, with their faulty lines and gradients, and bad materials imperfectly connected with the houses along their course. Houses hurriedly and badly built on yielding foundations cannot be effectively or permently sewered, and disjointed pipes readily afford the means of sewage saturation in

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foundation basements, if not in the upper walls, of a large proportion of the "jerry built" dwellings of a London suburb. The house so circumstanced may be for a time regarded as less liable to the entrance of sewer gas, because its virulence is absorbed in the soil and porous materials of which it is constructed, although in the long run it must essentially become a "diseased house."

There are, unfortunately for the London householder, none of the favorable conditions attached to his case which secure for the citizen of Edinburgh the advantages of a Sanitary Protection Society; and which, in the interest of public safety, has been extended to the metropolitan house dweller. There are obstacles of a formidable nature to be encountered; not the least of which consists in the fragile structural character of the house itself, which would, in too many cases, be incompetent to withstand the disturbing influence of the necessary works to ensure its sanitary perfection. The machinery of remedy offered by the new Sanitary Society, is quite voluntary, and may, we trust, exert some beneficial influence in dealing with favorably-circumstanced cases of an exceptional character. We are not hopeful, however, of seeing much improvement realized by its exertions, for the evil is too deep rooted for private enterprise to overcome or remedy. In the direction of guaranteeing sanitary perfection in newly-built houses there would be better prospects of success, for a dwelling so circumstanced would secure a rental higher even than the extra cost required for its invulnerability against disease.

In the absence of sufficient controlling authority London is allowed to extend itself in all directions, by the building of new houses, many of which, under proper challenge, would not be allowed to be built. There is a lamentable want of accord all round on this vital question, notwithstanding the abundance of remedial authorities, which would have but little employment or attention bestowed upon them, if the necessary primary measures of prevention were fairly considered and insisted upon.

Apart from what may be termed foreign or external danger, produced by the causes we have referred to, there are domestic and internal sources of diseases built with the house, and, like the ailments of a helpless child, inheriting parental taints, may be regarded as practically incurable. Walls (placed on manure-charged soil) composed of bricks, competent to absorb in many cases their own weight of moisture, and jointed with mortar produced from road sweepings and sometimes worse; timber, which if not primarily defective, speedily from its position becomes rotten, and walls plastered with porous and spongy materials, which have their surfaces covered with poisonous papers stuck on with vegetable paste, which soon engenders a fungus growth capable of destructive and malignant influences; the carpets, curtains, and indeed, every item of furniture of such a house, and the clothing of its inhabitants, are, in themselves, calculated to create disease, without the supplemental danger of sewer gas. Absence of ventilating appliances intensifies the dangers arising from the conjuction of so many formidable and, under the circumstances, uncontrollable evils. The windows and doors are *fortunately* not capable of being hermetically closed, which should be regarded as a signal advantage, for it permits of some degree of relief, by the entrance of air in and through this dwelling of undoubtedly "shoddy" surroundings.

London and its doings is looked upon by provincial cities and towns as a model for imitation, and in the matter of drainage we fear the lesson has been read too slavishly, leading to the general adoption of sewage disposal into sea or river outlets. What has been done in the Metropolis is considered a guide as to what should be done elsewhere, and so main drains, and wasteful and dangerous water outfalls, have become fashionable. Look, say the servile imitators of a vicious system, at the main drainage of London: it cost millions, and conveys away, in the most perfect manner, all the waste of so great a city. The bill for all this supposed comfort has not yet been settled, for suffering, disease, and death are still sending in their ever-recurring claims, which must be met, and while they continue to be presented, they record the incontrovertible fact that the source of their origin is due to a lamentable infringement and disregard of nature's laws.

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ADDITIONAL WIDTH OF GAUGE ON RAILWAY CURVES.

By THOMAS DOANE.

A Paper read before the Boston Society of Civil Engineers.

Some two or three years ago, an inquiry was made as to making the gauge of railroad tracks wider upon curves than upon straight lines. The editor asked for information upon that subject, but, so far as I know, the matter has had no further attention, though it is a *very important* one.

As long ago as 1870, in laying track, I widened the gauge upon curves, but having turned over the road to the operating department upon its completion, I had no opportunity to further study the experiment, and have therefore remained silent.

During a recent visit to the road referred to, I learned something further about it, which may, perhaps, be interesting to the members of our Society; certainly to those who have to do with railroads.

The experiment alluded to above was made upon the Burlington and Missouri River Railroad, in Nebraska.

Previous observation had shown me that, though the tracks upon the straight lines and upon the curves had been originally laid to the same gauge, the gauge upon the curves was soon widened out by use. I do not now remember whether my observation showed a movement of but one, or of both rails, but I concluded that the widening of the gauge was due to the *stiffness of our trucks*, and their failure fully to traverse upon the curves, and *not* to centrifugal motion. If this were the fact, it would even then be probable that the exterior rail of the curve would suffer the greater movement. Simple stiffness of trucks would be likely to affect both rails equally, but adding to this influence that of centrifugal force, unless it be *fully* counteracted by difference of elevation, and the exterior rail would show the greater displacement.

This condition of things showed a *want* of *fitness* between the track and the rolling stock, and a consequent unnecessary, if avoidable, wear and tear upon both, and a waste of motive power.

It seemed to me that if the moving trains were *bound to take more room* between the rails, that it would be better to *give* it to them *at the first*. Then the rails would be firmly seated and remain in their places. If this is not done, and the rails are laid to *straight line*, or *close gauge*, then the heads of the rails will be forced apart, the rails will be tipped on to their outer edges, either cutting into the ties or pulling their interior spikes, or both, thus loosening and disjointing the whole *permanent* way. So long as the gauge remains too narrow for the trains, there must result from the friction between the wheel flanges and the rails great wear and destruction of both.

If the gauge of curves be made open and loose, the *coning* of wheels will be utilized.

And, further, an engine will haul a larger load than if the train is pinched between rails too closely laid.

And, what is perhaps of more importance than anything else, *greater safety* is secured upon a track with an *open gauge*, in which the rails are firmly secured in the places where they are to remain, than upon a loosened and deformed track.

Upon the main line of the Nebraska road, the curve of greatest radius is a 30′ curve, and of least radius a 3° 30′ curve. In laying tracks on *all curves* of *less* than 2° the gauge was increased from straight line gauge $\frac{1}{4}$ *inch*, or to 4 feet $8\frac{3}{4}$ inches, and 2° curves add over were laid to a gauge of 4 feet 9 inches, being an increase of $\frac{1}{2}$ *an inch* over straight line gauge. *Three* sets of gauges were furnished the section men, of the lengths stated above for the curves, with the usual straight line gauge of 4 feet $8\frac{1}{2}$ inches, and the men were held to the use of them, until the road was turned over to the operating department by the engineering and constructing department.

At that time a new road-master came in, who either did not understand, or did

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not appreciate what had been done by his predecessors, and curved track was gradually brought to the straight line gauge of 4 feet 8½ inches.

Since this road-master left, the tracks upon the curves, while undergoing repairs, have been restored to their original gauges, and have so remained now for several years. The man now in charge says that the practice gives great satisfaction; that the tracks upon the curves are maintained in *good condition*, at very little expense; that the *wear* of rails is sensibly diminished; that the engines can haul a *maximum* load, and that *no accidents* have occurred from increasing the gauge.

I have been told that, on hearing of laying track with open gauge upon curves, the officers of the Atcheson, Topeka, and Santa Fé Railroad adopted the plan for their road.

As there was but one curve on the Nebraska road of shorter radius than that of a 3° curve, no attempts were made to widen gauge, more than the ½ inch alluded to. I have no doubt, however, that it would be entirely safe and wise to widen to the extent of one inch, or slightly more. The tread of our railroad car wheels is sufficient to prevent the wheel from dropping from the rail even then, and if laid 1½ inches open, the tread of the wheel, as now made, would cover about all of the tread of the rail.

Since writing the above I have had occasion to refer to the matter of resistance of curves to trains; and in an article by Baron Von Weber I find the subject of *widening gauge* on curves *incidentally* alluded to. I was therefore mistaken in saying that the matter had no further attention since the inquiry of the *Gazette* had been made, but as it did not appear under a head distinctly bringing the *subject* to notice, it may have escaped the eye of the original inquirer, as it did mine.

The experiments of Von Weber were made in 1876-7-8, and his article entitled "Train Resistance on Curves" appeared in the *Railroad Gazette* of June 11, 1880.

Item No. 9 of a summary of the above is as follows: A reduction of the additional width of gauge on curves customary on the Bavarian roads, one half or more, contrary to expectation, caused an increase in the resistance. The additional width given on these roads is:

Radius of meters.	Radius in feet.	Degree of curve	Additional width of gauge in meters.	Additional width of gauge in inches.
750 M	2482 ft.	2° 18′	0.008 M.	0.32 inch.
550 "	1822 "	3° 9′	0.014 "	0.56 "
400 "	1320 "	4° 20′	0.020 "	0.80 "
300 "	993 "	5° 45′	0.025 "	1.00 "

This result, however, cannot as yet be considered as fully established. This is the end of the quotation.

It would seem, then, that the widening of curve gauge upon the railroads of Bavaria is now usual, but how far back the custom extends is not shown by Von Weber's article.

It appears from the experiments that the *reducing* of the *additional width* of gauge increased the resistance to the passage of trains. The converse would therefore be true, within certain limits, that an additional width of gauge would decrease the resistance. This is in accordance with my own theory and experience, and it is to be hoped engineers will give the matter further attention and experiment.

The gauge of the tracks of Bavarian railroads is not given in Von Weber's article; but presuming it to be not very different from the standard American of 4.71 feet, there seems to be a very close agreement between the additional widenings which I gave the curves of different degrees in 1870, and those which are now used on the Bavarian railroads.

If I had been living in a country, or at a time, when engineers were expected to think and work in *metrical terms*, there *might* have been a still closer agreement.

REPORTS OF ENGINEERING SOCIETIES.

THE AMERICAN SOCIETY OF CIVIL ENGINEERS.—The last issue of "Transactions" contains paper No. 217, "On the Ventilation of Halls of Audience," by Robert Briggs.

At the meeting of the 4th of May, held at the new quarters of the Society, a paper on "Quicksand in Excavation" was read by Charles L. Mc Alpine.

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ENGINEERS' CLUB OF PHILADELPHIA.—The last number of "Proceedings" contains papers as follows:

No. 7. "The Panama Canal and Isthmus," by Col. James Worrall.

No. 8. "The Strength of Wrought-Iron Columns," by Thomas M. Cleeman.

No. 9. "Progress of the Second Geological Survey of Pennsylvania," by Charles A. Ashburner.

No. 10. "Intercommunications in Cities," by Prof. L. M. Haupt.

At the meeting of May 7th, Mr. Rudolph Herring gave a general account of a recent examination of the sewerage systems of European cities.

ENGINEERING NOTES.

THOUGH it is impossible that a Channel tunnel railway can ever pay, unless some genius in railway management arises to show how trains can be made to follow through the tunnel at more frequent intervals than they do at present on the Metropolitan Railway, and also to persuade more millions of passengers to travel between England and France than now travel on the great London underground system, the South-Eastern Railway Company is still spending money boring in into the chalk near Abbot's Cliff. Already it is stated that a 7 foot heading of 300 yards on a sharp gradient has been cut by one of Brunton and Trier's boring machines made on the principle of their stone dressers, and Colonel Beaumont, R. E., is busy on the work. A small steam pump is sufficient at present to keep the water under, but the heading is yet only at about low water tide level, and doubts of the entire freedom from shakes or fissures of large size in the chalk are not altogether absent. Does Sir E. Watkin think he is going to frighten the shareholders in the London, Chatham, and Dover by this costly little experiment?

RAILWAY NOTES.

MOUNTAIN RAILWAYS.—The *Génie civil*, a new French publication, to the recent appearance of which we lately referred, has in one of its earlier numbers a description of an improved system of mountain railways entirely original in its conception. It is well known that the construction, maintenance, and working of mountain railways have long occupied the attention of engineers. Many methods of climbing steep inclines and of rounding curves of small radius have been proposed, and several of these methods have been reduced to actual practice. The systems of Fell and Riggenbach are very well known, and the ancient system of rope tramways is in use in many places. A French engineer, M. L. Edoux, has conceived a project which is based upon the application of a system of hydraulic elevators to the lifting of cars to any height. This system may be applied to great advantage when an abundance of water under high pressure is available. These conditions will be frequently met in a mountainous country. Although this project has not yet been realized, it seems to possess sufficient merit and novelty to render it interesting to our readers.

The particular railway under consideration is intended to establish communication between Cauterets and the baths of La Raillère, in France. Cauterets is situated in a narrow valley, at an elevation of more than 2800 feet. It is a noted watering-place, and during the season is filled with numbers of invalids, who go there in search of health. The hot sulphur springs, for which this region is noted, are located at La Raillère, 400 feet higher up the mountain, and nearly a mile distant by road. To travel over this fatiguing route, to go and return, often twice in the same day, in the capricious weather of the mountains, and in the crowded omnibuses, is uncomfortable and even dangerous for infirm persons. The waters cannot be conveyed from La Raillère to Cauterets without modifying their temperature and their chemical composition, to which their therapeutic properties are due. It is therefore necessary to convey the sick to the springs that they may receive the full benefit of the waters. This railway has been projected for the purpose of conveying the bathers from Cauterets to La Raillère rapidly and comfortably. All systems, with the exception of that of M. Edoux, require the consumption of a large amount of fuel, which in this region is very expensive. This inventor utilizes the powerful waterfall at La Raillère, which, in connection with gravity, constitutes the motive power of the railway.

The proposed mode of working the railway is as follows: The car is raised vertically by means of hydraulic elevators to a greater height than its destination, which, in the present case, is La Raillère, and is then allowed to descend as far as that place by its own gravity upon an inclined railway. To return, the car is transferred by its own gravity to a second railway inclined in the opposite direction. The cars are provided with efficient brakes, by means of which the speed may be effectually controlled. In practice, the car is not raised the vertical distance 400 feet at a single lift, but this distance is divided into five parts of 80 feet each. There are five towers at intervals of about 130 feet. In each one it is proposed to place an hydraulic elevator, similar to those introduced by M. Edoux into the hotels and houses of Paris. The top of each tower is a little more elevated than the foot of the next one, and is connected with it by an inclined bridge. The car is raised by the hydraulic elevator to the top of the first tower, runs by its own gravity to the base of the following one, is raised to the next level, and so on. Together they form a gigantic staircase, with steps 80 feet high. The last landing place is 420 feet above Cauterets. The return way, which is on the side of the mountain, terminates in the second tower. The cars descend vertically only in the first two towers, which contain two compartments, one for hoisting the car and one for lowering it. At La Raillère the inclination of the car is reversed, and the car is transferred to the return track by means of a platform supported

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on wheels and provided with rails. The car on arriving from Cauterets rolls upon the platform. The latter moves by its own gravity on rails slightly inclined in opposite directions, so that, when the rails of the platform join the return track, their inclination will have been reversed, and the car will, of its own gravity, return to the second tower. The movement of the transferring car is controlled by an hydraulic piston. The gradient of the railway is very slight, just enough to supply an impetus.

OBSERVATIONS on the part of different railway men do not agree as to the relation between season and the breakage of rails. In a recent issue of the *Organ fur die Fortschritte des Eisenbahnwesens*, Herr Theune states the results of his observations with respect to the fractures of steel rails in the district—Kattowitz—under his observation. He notes that 329 such fractures took place during the years in which his interesting observations were made. Among the rails which were laid in the open country there were 2.4 fractures per mile, while in forests, where rails are exposed to greater damp, the rate rose to 6.7 per mile. The changes of the various seasons have a striking influence on the number of breakages which take place. Thus, during the first quarter of the year—the coldest season generally—there were 216, in the second quarter 28, in the third quarter 14, and during the fourth quarter 71 fractures. The greatest number of fractures of rails took place from the eighth to the tenth years after their having been laid down; the average working time was found to be 7.5 years. With respect to the parts where fractures took place, Herr Theune remarks that there were 73 fractures in the face of the rail, 51 breakages in the web, and as many as 265 fractures through the fish-plate holes. The very great excess of fractures in the first quarter seems to indicate error in observation or in the accounts consulted.

IRON AND STEEL NOTES.

THE report of the North British Railway Company for the meeting on the 31st inst., shows that the company now possesses of effective stock 470 engines, 426 tenders, 297 first-class carriages, 67 second-class, 662 third-class, 178 composite, 140 horse boxes, 148 passenger luggage vans, 1 post office, and 1 meat van, 101 carriage trucks, 1 horse carriage, or 1596 in all. The effective stock in the wagon department includes 27,866 vehicles of all kinds. The total number of miles of line worked by the company's stock and engines, including those rented and worked over, is 1085½, the miles owned by the company being 870. The total train mileage in the half year ending 31st January was: passenger trains 2,278,652, and of goods and mineral trains 2,776,618. The locomotive power cost, including all expenses, £129,577 14s. 8d.

IT has been remarked in the money article of the *Times* that "there is a good deal of comment in the market on the fact of the North British Railway directors declaring a dividend on the Ordinary stock in present circumstances. A full explanation is called for as to the mode of dealing with the finance of the new Tay bridge. When the accident happened the directors wrote off £120,000 at once, partly at the expense of the Preference shareholders, about whose losses there was a great deal of outcry at the time. But if the old bridge is to be virtually condemned, even this £120,000 is not sufficient; the whole cost, which was over £300,000, ought to be written off. If a new and wider bridge is built the excess of cost to build it as compared with the cost of the old bridge may, perhaps, be fairly charged to capital; but whatever has been really lost, must be made good out of revenue. The question is of general interest in railway finance, and we trust a complete account will be given of what is going to be done, and the reasons for it."

THE Aireside Hematite Iron Company, which has introduced concrete slag as a substitute for stone, has erected new offices at its works in Hunslet, Leeds, in which all the door and window facings, and the ornamental work, are composed of the slag from its own furnaces. A new feature of such an elevation is a display of imitation carved bricks, in various colors, made of the slag, the cost of which is said to be 50 per cent. less than the real article of clay which hitherto has been so much in fashion. The Aireside Company is, we are informed, supplying the Midland and North-Eastern Railway Companies with slag concrete flags, ready prepared for use, in the laying down of platforms at railway stations. The Staveley Company has for a long time used slag lumps for building purposes, much of the slowly-cooled massive slag having the appearance of basalt and other rocks.

ORDNANCE AND NAVAL.

MACHINE GUNS AT SHOEBURYNESS.—The trials which have been carried on intermittently during the last six weeks at Shoeburyness with the Gatling, Nordenfeldt, Pratt-Whitney, Gardner, and "improved Gardner" machine guns were brought to a close on Feb. 22nd. The guns thus tried have been of two classes, the "light," for ship and boat service, and the "heavy," for service in the field. There were originally three light guns, the two-barreled Gardner, weighing 100 lbs., the five-barreled Nordenfeldt, weighing 143 lbs., and the six-barreled Gatling, weighing 200 lbs. The heavy guns were the five-barreled Gardner, weighing 302 lbs., the ten-barreled Nordenfeldt, weighing 256 lbs., the Gatling, weighing 254 lbs., and the Pratt-Whitney, weighing 261 lbs. The six-barreled Gatling was withdrawn from its failure to fire the 1000 rounds test. There were two series of penetration trials. The first series was at 20 targets an inch in thickness, placed at intervals in rear of each other, and shots were taken at these at 300 yards. The results were not entirely conclusive, as some of the shots hit nails, and so were stopped; but while one shot of

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the five-barreled Gardner indented the last target but one (the 19th), others indented the 16th, while the two-barreled lodged a shot in the 14th. The Gatlings lodged shots in the 12th, 13th, 14th, 16th, and 17th, the five-barreled Nordenfeldt lodged one in the 13th, three in the 16th, and one on the 18th, the ten barreled Nordenfeldt lodging its shots between the 14th and the 16th. One Pratt-Whitney shot lodged in the 17th target, while others stayed between the 10th and 13th. The trials at the steel plates, in which the target was formed of two steel plates, "sandwiching" an inch of deal, gave the important fact that at 300 yards the bullets of most of the guns would penetrate the steel of torpedo boats. The "elevation" trials, when the guns were elevated to 30°, were taken in the shed, and the shots fell to seaward. The ammunition running short, all the barrels of the ten-barreled guns were not fired, but it was apparent that the Gatling could not feed at this degree of elevation, and the ten-barreled Nordenfeldt, though it was fed at this elevation, required manipulation, the hopper not being made to suit more than 20°. All the other guns worked successfully, and they all worked in the depression trials without hitch—these being also at 30°. The "rough usage" trials were then made, one of these being the sifting of sand above the guns. The sharp grit of the flint sand from the seashore soon penetrated to the works of the guns and stopped them one after another by choking the chambers. This was the most severe trial which the guns had. The guns were then dismounted and dragged by Royal Artillerymen in the ditches, which were full of mud. They were then handed over to the inventors, each inventor being allowed the use of a bucket of water, a brush, a screw driver, and some oil. The time was taken in which the guns could be cleaned and could fire three "feeds." The two-barreled Gardner was cleaned and had fired sixty rounds in 3 min. 32 sec. The ten-barreled Nordenfeldt was cleaned and had fired 300 rounds in 6 min. 20 sec. The five-barreled Gardner was cleaned and had worked out 150 rounds in 4 min. 21 sec., but fifty-five of the rounds passed through unfired owing to the water in the gun block not being drained off, this retarding the firing spring. The five-barrelled Nordenfeldt was cleaned and had fired 150 rounds in 3 min. 28 sec.—*Times.*

THE RUSSIAN NAVY.—The St. Petersburg correspondent of the *Times*, writing on the much controverted subject of the "Livadia," says: "The old dispute between the partisans and opponents of Vice-Admiral Popoff is not yet exhausted, nor has the Russian public heard the last of the famous turbot-fashioned yacht "Livadia," still lying useless at Ferrol. It now appears that the Russian naval authorities have set their minds upon encasing the "Livadia" in wood, as soon as her damage has been repaired and she can be got safely into the Black Sea. It is, therefore, difficult to imagine what will eventually become of this novel and ill-fated vessel, or how much more expense will have to be added to the original cost before she will be complete in the opinion of Admiral Popoff. In all probability, whatever may be the improvements made, she will never do much more than take her place by the side of the circular hulks which originated in the same ingenious brain, and furnish another curiosity in the Black Sea. It does not seem that she will enjoy the privilege of carrying the new Czar to the Crimea, for the latest report gives it as the intention of the Imperial Admiralty to build another yacht of steel of the same kind as the old yacht "Livadia," which foundered off the Crimean coast. In any case, the success of the "Livadia" seems more than ever doubtful. The version of the damage done to her bottom, as given at the time by Sir E. J. Reed and others, has not been borne out by the independent Russian authorities who have gone into the matter. On the contrary, the floating wreckage theory is flatly contradicted here. The "Livadia" has, or had, several large cracks, one being as much as 10 feet long and 1 foot wide—a hole which it is impossible to repair without a dock. This being the case, and in view of the fact that the sides or ribs of the fore part of the vessel are damaged or strained, it is impossible, the Russians say, that wreckage alone could have been the cause of the accident. Moreover, it is observed, the screws and their appurtenances would inevitably have been considerably damaged by floating wreckage passing under the ship, and this is not found to have been the case. This matter of the "Livadia," however, forms only a small part of the general accusation which the Russian press has brought against the Imperial naval authorities. Excessive expenditure with the meanest results in naval progress is the theme of the *Golos*. 'The Naval Budget of Russia for the ten years between 1870 and 1880, when compared with that of England for the same period, shows that, although the sum spent by Great Britain on naval construction was only between two and three times more than the amount expended by Russia on the same account and for the same time, England acquired six times the number of new vessels that Russia did, to say nothing of their quality. For the ten years ended with 1880 the Russian Ministry of Marine spent 298,920,910 roubles, of which 72,000,000, or only 26 per cent of the whole sum, was devoted to ship-building proper. For this sum Russia got the "Peter the Great," the two "Popofkas," three frigates, eight clippers, four cruisers from America, four Imperial yachts, including the "Livadia," four schooners, nine gunboats, two torpedo boats fit for sea, and 115 torpedo sloops unfit to leave the coast. In other words, after putting aside the two "Popofkas" and other smaller vessels good for coast defence only, the Russian fleet was augmented for the above amount by only one ironclad, three semi-ironclads, twelve other seagoing vessels, and four yachts for passenger service. A glance at English expenditure on naval construction for the same decade shows that for £19,200,000, or 170,213,000 roubles, we acquired twenty-four ironclads, three frigates, thirty corvettes, fifty-two clippers, fifteen gun-

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boats, six transport vessels, and a large number of smaller vessels for coasting service. The Russian Naval Budget is the third in the world, but the facts just mentioned show how little the Russian Government gets in reality for its enormous outlay on naval improvements and novelties.'"

[Sir Edward J. Reed, in replying to the above letter, as far as it concerns the "Livadia," states that the correspondent is in error in supposing that the Russian authorities contradict him when they say that "wreckage alone would not have caused the accident" to the "Livadia," when they include under the word *accident* all the damage and straining at the fore part of the vessel. Much of this damage and straining, Sir Edward affirms, was due, doubtless, to the absence of certain reverse frames and other details, of the necessity for which he spoke quite freely both before the ship left the Clyde and after she arrived at Ferrol. The wreckage theory was resorted to as an explanation—and what to Mr. Pearce and others on board seemed the only explanation—of two holes with which the bow bottom had been pierced in its very strongest part. These holes, he was obliged to admit, bore every appearance of having been caused by wreckage—as if by the iron cross trees or other fittings of a floating wooden mast, for example. With these holes manifest to their eyes, he certainly did not think it necessary to insist publicly upon his own view of the local weakness of the bow, resulting from the absence of reverse frames, &c., especially as these were mere matters of detail which could be readily put right at Sebastopol. Sir Edward Reed continues: "I do not think Admiral Popoff can much complain of the adverse inferences and comments which have resulted from the ship having been made to winter at Ferrol. Although a mere visitor on board, I did all I could to avert what was certain to occasion a general distrust of the ship. But Russian ways are not our ways, and the ship remained, the reputation which her great and original qualities ought to have secured for her being sacrificed to mere matters of detail and convenience. Such a mode of dealing with such a ship is, I confess, enough to justify grave distrust in other respects. At the same time, I must say, in common fairness, that the proposal to sheathe the immersed hull with planking, to be afterwards coppered, is not at all an after thought, but formed part of Admiral Popoff's original intention. This I state from personal knowledge."]

BOOK NOTICES

Publications Received.

The Monthly Weather Review for April. Washington: Government Printing office.

Progress of the Works of Completion of the New Improved bed of the Danube at Vienna. By Sir Gustave Wex. Translated by G. Weitzel, Maj. of Engineers and Bvt. Maj. General. Washington: Government Printing Office.

Professional Papers of the Corps of Royal Engineers. Vols. IV. and V. London: Royal Engineer Institute.

Annual Report upon the Surveys of Northern and Northwestern Lakes, in charge of C. B. Comstock, Maj. of Engineers and Bvt. Brigadier-General. Washington: Government Printing Office.

Evansville Water Works. Report of the Expert (John W. Hill) on the Trials of the Gaskill. Compound Pumping Engine. Cincinnati: Robert Clarke & Co.

Rrport of the Expert on the Test Trials of Automatic Cut-off Steam Engines, at the First Millers' International Exhibition at Cincinnati, June, 1880.

The Telescope: The Principles Involved in the Construction of Refracting and Reflecting Telescopes. By Thomas Nolan, B. S. New York: D. Van Nostrand. Price 50 cents.

This is a reprint from the articles on "The Telescope" in the first three numbers of this magazine for the current year. It forms No. 51 of Van Nostrand's Science Series.

The author claims no originality except for the form in which the subject is presented. To all who are familiar with the elementary principles of geometry and of optics, the construction of the telescope is made exceptionally plain.

The author is particularly happy in his method of explaining the theory of the various eye-pieces, and in elucidating the obstacles encountered in dealing with the Secondary Spectrum in large Refracting telescopes.

The illustrations are for the purposes of demonstration, and are very good.

Graphical Determination of Forces in Engineering Structures. By James B. Chalmers, C. E. London, 1881. For sale by D. Van Nostrand. Price $6.50.

This is something more than a practical application of Graphic Statics to Structures, for it presents quite clearly the theoretical principles of the science.

Its chief value to engineering students, however, lies in the fact that it presents applications to other problems than those relating to framed structures. Retaining walls, tunnels and voussoir arches receive a fair share of attention.

A complete treatise on Projective Geometry, which forms the ninth chapter, will prove interesting to mathematical students, as it presents a summary of the various theorems of modern geometry collected from the works of many authors, and upon which the science of graphic statics is founded.

Induction Coils—How made and how Used—Science Series No. 53.—New York: D. Van Nostrand. Price 50 cents.

This useful little treatise has reached its eighth English edition, and it is this last which is now reprinted for the American market.

The "Induction Coil" is now to be obtained of any dealer in physical apparatus and

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at a price which is rapidly extending its use by teachers.

Many experimenters are imperfectly acquainted with the resources of this instrument, and can get but imperfect suggestions from the text books in common use. To supplement such books is the object of this little handbook. It is abundantly illustrated, and the directions for the selection or construction of batteries, and the preparation of experiments with the coil, are of the most specific kind.

PRACTICAL ORGAN-BUILDING. By W. E. Dickson, M. A. London: Crosby Lockwood & Co. For sale by D. Van Nostrand. Price $2.00.

The work is designed as a guide to amateurs, and gives specific directions in the matter of constructing the parts in detail.

The contents present the following topics:

Chapter I. Plant and Materials.
II. The Stopped Diapason.
III. The Sound-Board.
IV. The Sound-Board.
V. The Wind-Chest.
VI. The Bellows: Trunks and Frame.
VII. Plantation of Pipes.
VIII. The Action.
IX. Voicing and Tuning.
X. The Draw Stops.
XI. Pedals.
XII. Two-Manual Organs.

THE PLUMBER AND SANITARY HOUSES—(Second Edition.)—By S STEVENS HELLYER. London: B. T. Batsford. For sale by D. Van Nostrand. Price $4.00.

With the wide demand for an improved method of house drainage there has arisen, quite naturally, a demand for a better knowledge of the conditions to be met and the evils to be avoided.

The work before us is chiefly remarkable for the directness with which the author attacks the problem of house sewage. There are no pages wasted on theories of ventilation or drainage, but with the briefest possible statement of what is to be done, the author proceeds to point out how, through ignorance, people often fail to do it, and appealing to common sense and an elementary knowledge of physics he exhibits to the reader the various correct ways of avoiding the common errors.

The illustrations are numerous and exceptionally well designed to exhibit the various approved sanitary appliances.

THE WOOL CARDERS VADE MECUM—By WILLIAM CALVERT BRAMWELL. Third Edition. Boston: Thayer & Wadham. For sale by D. Van Nostrand. Price $2.50.

A work designed for a class interested in a single industry only. The present edition is prepared with considerable matter not in the previous editions, in response to demands for a more comprehensive work.

It now contains:

Part I. "Animal Fibres," "Vegetable Fibres," "Re-manufactured Fibres."

Part II. "Wool Washing," "Wool Blending," "Wool Oiling."

Part III. "The Carding Engine," "The Carding Process," "Practical Operations."

Part IV. "Appendix," "Tables," &c. "Historical Review."

LATHE WORK—By PAUL N. HASBUCK. London: Crosby Lockwood & Co. For sale by D. Van Nostrand. Price $2.00.

There are many amateur lathe workers, whose labor would yield more satisfactory results if they had at hand a convenient manual like the one here offered. The directions are explicit, and from one who understands the difficulties usually met, and how to overcome them.

CONTENTS:

I. The Art of Turning.
II. The Foot Lathe.
III. Hand Turning.
IV. Screw Cutting by Hand.
V. Boring and Drilling.
VI. Mounting Work for Turning.
VII. Fitting Chucks.
VIII. Various Chucks described.
IX. Slide Rests.
X. Slide-Rest Tools.
XI. Slide-Rest Cutter, Bars.
XII. Overhead Gearing.
XIII. Dividing Apparatus.
XIV. The Drilling Spindle.
XV. Vertical Cutter Frame.
XVI. Screw Cutting by Self-acting Motion.

STEAM BOILERS; THEIR DESIGN, CONSTRUCTION AND MANAGEMENT. By William H. Shock, Engineer-in-Chief, U. S. N., Chief of Bureau of Steam Engineering, U. S. Navy New York: D. Van Nostrand; London Sampson Low, Marston, Searle and Rivington.

Of this extensive work, noticed some time since in this journal, our English contemporary, "Engineering," in giving a summary of the topics treated says:

"The very handsome volume before us has, apart from its intrinsic merit, a special interest from that the fact the position of its author gives it a semi-official character, and entitles it to be regarded as an exponent of the most advanced practice in the United Navy. In fact, although the earlier part of the work treats of theoretical principles applicable to boilers generally, yet those chapters which treat of constructive details relate chiefly to American marine practice. That this fact will in no way detract from the interest of the work to English readers we need scarcely say. All engineers who are acquainted with the working of the Bureau of Steam Engineering of the United States Navy well know that there have been carried out under the auspices of this Bureau numerous series of researches which have added much to our stock of data bearing upon steam engine and boiler construction, and this being so a work which embodies the results of many of these researches has a pecial claim to our attention.

* * * * *

Altogether, Mr. Shock has produced a book which forms a most valuable addition to the engineer's library, embodying as it does an able summary of the best European and American practice, in addition to the results of the author's own practical experience. We

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should state, also, that in addition to numerous engravings in the text the work is illustrated by thirty-six well-executed plates of boilers and boiler details (the latter drawn to a large scale), while as a specimen of typography it is admirable."

MISCELLANEOUS.

THE CORROSION OF IRON IN BOILERS.—The oxidation of iron immersed in ordinary water appears to be largely due to two causes, namely, first the absorption of oxygen contained in the water, and second, the absorption of oxygen set free during the decomposition of the water, hydrogen being set free in the latter case. M. Lodin, who has made a number of experiments on the corrosion of iron wires immersed in water and various solutions, and who has described his experiments in the *Comptes Rendus*, has arrived at the conclusion that the first of the above causes of oxidation is generally of chief importance. With both distilled and ordinary water the temperature has a very important influence. Thus at 68 degrees Fahr. the quantities of oxygen absorbed per square foot of iron surface per hour when immersed in distilled and calcareous water, respectively, were 0.258 grains and 0.330 grains, while at 212 degrees the quantities rose to about 2.364 grains and 2.579 grains. The immersion of iron in all the waters tested was accompanied by the evolution of hydrogen, the action being least, however, in distilled water. At a temperature of about 260 degrees Fahr., the decomposition of the water was found to be equivalent to the absorption of 0.01 grain of oxygen per square foot of surface per hour for distilled water; 0.0129 grain for calcareous water; 0.0182 grains for water containing one-fifth part of crystallized chloride of magnesium: 0.05 grain for water saturated with chloride of sodium; and 0.067 grain for sea water.

THE GREAT BRUSH LIGHT.—One of the most powerful electric lights ever yet produced was recently exhibited at the factory of the Anglo-American Electric Light Company in Vine street, York-road, Lambeth. This magnificent artificial sun was the second ordered by the Admiralty for service in torpedo work, and was despatched to Portsmouth on Tuesday morning. The light is generated by a sixteen-light machine, and the lamp is of the ordinary Brush type but of unusual size. Each of the field magnets of the machine contains 800 lbs. of silk-covered copper wire. The current was led off by four copper combs each 5 inches wide, and consisting of 16 stout copper teeth, and was taken to the lamp by a ⅜ inch copper rope lightning conductor. A Brotherhood engine of 15 horse power drives the machine, being mounted on the same baseplate, and the absolute steadiness of the light is sufficient proof that this type of engine is admirably adapted for the purpose to which it is being very largely applied. The carbons of the lamp are 1¼ inches in diameter, and, such is the extraordinary energy of the current, they are heated white hot at a distance of 2 inches from the arc. A silvered parabolic reflector 3 feet in diameter was placed behind the arc, and projected the light, which was displayed upon the roof of the factory, in a broad divergent beam of great power. The photometric power of the light is stated by the Anglo-American Electric Light Company to be 47,000 standard candles.

IN a note to the Vienna Academy—*Anz.* December 16th—Prof. Stefan describes experiments on the influence of terrestrial induction in development of an electric current, and the excitement of the telephone by currents from a rotating coil. The coil used was 56 mm. in external diameter, and 11 mm. in width. The earth's influence is best shown by so connecting the apparatus with a galvanometer that the circuit is closed during one-half of the coil's rotation, and broken during the other half; if the completion of the circuit corresponed to the positive maximum of the electro-motive force of the earth's magnetism, and the interruption to the negative, the galvanometer is positively deflected. The deflection may be reduced to zero by displacing the contact, and from the displacement and the number of rotations the potential may be inferred in absolute measure. Next, the telephone was so connected with the coil that the full alternately opposite currents went uninterruptedly through the circuit. This gave a simple tone. With 100 rotations per second the horizontal component of the earth's magnetism did not suffice to excite an ordinary telephone, but it excited one having a horseshoe magnet. When the intensity of the field was doubled the ordinary telephone was also excited. The tone corresponds to the number of rotations. When the coil was rotated 220 times in a second the ordinary telephone sounded. The telephone was shown to be less sensitive to currents whose intensity periodically changes than to interrupted currents—an ordinary telephone sounded with 100 rotations or fewer, when the circuit was closed only during a short time of each rotation.

BOUDET'S MICROPHONE. — A convenient form of microphone for telephonic purposes has been contrived by M. Boudet, of Paris. It consists of a mouthpiece for speaking into, closed by an ebonite disc. one millimeter in thickness. This is the vibrating plate, and carries behind it, attached to its center, a copper plug or piston which presses upon a row of six round pellets of retort carbon filled into a glass tube so as to be in contact with each other. The last pellet rests on a second plug of copper which in turn rests against a delicate spiral spring at the end of the tube. By means of a thumbscrew the force of this spiral spring can be regulated so as to produce the pressure of the microphonic contacts requisite to give the best articulation. The current from six Gaiffe, or chloride of zinc and manganese cells, is sent through the pellets, and the vibratory pressure of the diaphragm upon the pellets gives rise to the undulations of current which passed through the telephone are heard as articulate speech. The whole instrument is mounted on a jointed stand which accommodates it to the speaker.

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"THANK GOD FOR COMPOUND OXYGEN."

This is the grateful utterance of the wife of a clergyman. Her letter, dated New City, Rockland County, New York, June 14, 1880, thus states the condition of her husband when he began the Oxygen Treatment:

"Rev. A. J. Conklin, Pastor New City and Centennial Churches, Newark Conference, *was run down with overwork; voice injured, memory impaired, eyes very badly impaired, so that he could scarcely follow up general reading, much less study; throat affected, and the whole system in a bad state.* He would have had to stop preaching had he not found help. I asked him this morning what I should say in reporting progress to you for him. 'Oh,' he says, '*tell them I am well. Never felt better in my life!*' This on the minister's 'Blue Monday,' *after preaching three times on a very hot day, administering the sacrament and baptismal service, and walking three miles afterwards!* And now he is at work in his garden. *Thank God for Compound Oxygen!*"

A PHYSICIAN'S REPORT.

Many physicians are using Compound Oxygen in their practice, and with remarkable success. One of them writes:

"My patient has now been under treatment about four weeks. His condition at *the time of beginning the Treatment was very unfavorable indeed;* he was very feeble, severe cough, expectorating pus in considerable quantity; he suffered with night sweats; all of his friends considered his case as hopeless. *Every symptom has improved; his cough is very much better; his strength and general appearance has improved a hundred per cent., in fact, he has the appearance of a new man.*"

A BLESSING TO HUMANITY.

A lady residing in Georgia, whose son was threatened with consumption, wrote to one of our old patients, Mrs. M. T. Piersol, of No. 1636 Wallace Street, Philadelphia, asking if a testimonial in favor of Compound Oxygen, to which she saw her name attached, was genuine, and received the following reply:

"Yours just received. It is my privilege to say, in reply to your inquiry about the Compound Oxygen Treatment, that it is all it claims to be, and in some cases has exceeded its promise. My testimonial is genuine; and I am always glad of the opportunity to give my voice in favor of so *great a blessing to humanity.* As to your son's case, I would say, Persevere by all means. I think he has everything to expect; of course I cannot judge intelligently for him; but he can rely with all confidence upon Dr. Starkey's word. *I have known him for years. He is an intelligent and faithful physician* and a true man. I would advise you to keep him posted, and follow his directions strictly."

"WONDERFUL, WONDERFUL MEDICINE!"

So exclaims a patient, Rev. J. S. Fesperman, of Statesville, North Carolina. Writing June 2d, 1880, he says:

"In the Providence of God I owe my present state of health to your Oxygen. I was near the gate of the grave, and, as I believe, close to the great portals of eternal life, *when I commenced taking what I now consider the greatest of all healing agents, Compound Oxygen.* I cannot refrain from saying, '*Wonderful, wonderful, wonderful medicine!*' Physicians and friends had believed that I could not live any length of time, and I am here yet, with my large family of children, and able to walk from three to four miles every morning. I cannot speak in terms too high of your remedy."

AN EDITOR'S TESTIMONY.

Mr. R. P. Lewis, of East Saginaw, Michigan, writing to the editor of the Laporte (Ind.) *Argus*, says:

"I wish you would allow me to say, over my own signature, a word in behalf of a remarkable curative agent—Compound Oxygen. It is not a medicine but a vitalizer, and its effects are natural, direct and permanent. Its use involves no risk or inconvenience of any kind. I speak both from observation and experience. I was induced to try it by the recommendation of such men as T. S. Arthur and Judge Kelley, and also a personal friend, *and have found it more than was promised,* This was over six months ago, and the *good effects have been permanent.* A gain of fourteen pounds in six weeks was the avoirdupois result, but my general spirits were lightened up at least a ton. There are three other men here who have tried the Compound Oxygen with even more striking results, and I am acquainted with the history of each case. One of them lost his voice last winter, and was so run down in general health that little hope was entertained of his recovery. The Oxygen cured him without change of climate or stopping work, and he says he is as well as ever. Another, who had worked for years as paying teller in a bank, and was all used up and not expected to live beyond a month or two, took the Treatment, and is a hundred per cent. better and recovering rapidly. Another who was in the latter stages of Consumption, has tried it, and is greatly improved. *He tells me he would have been dead long ago but for this remedy.* I have no axe to grind in making this statement, and if you should not publish it I would lose nothing by the refusal, though if you should others might be benefited, which is all the end I have sought to compass."

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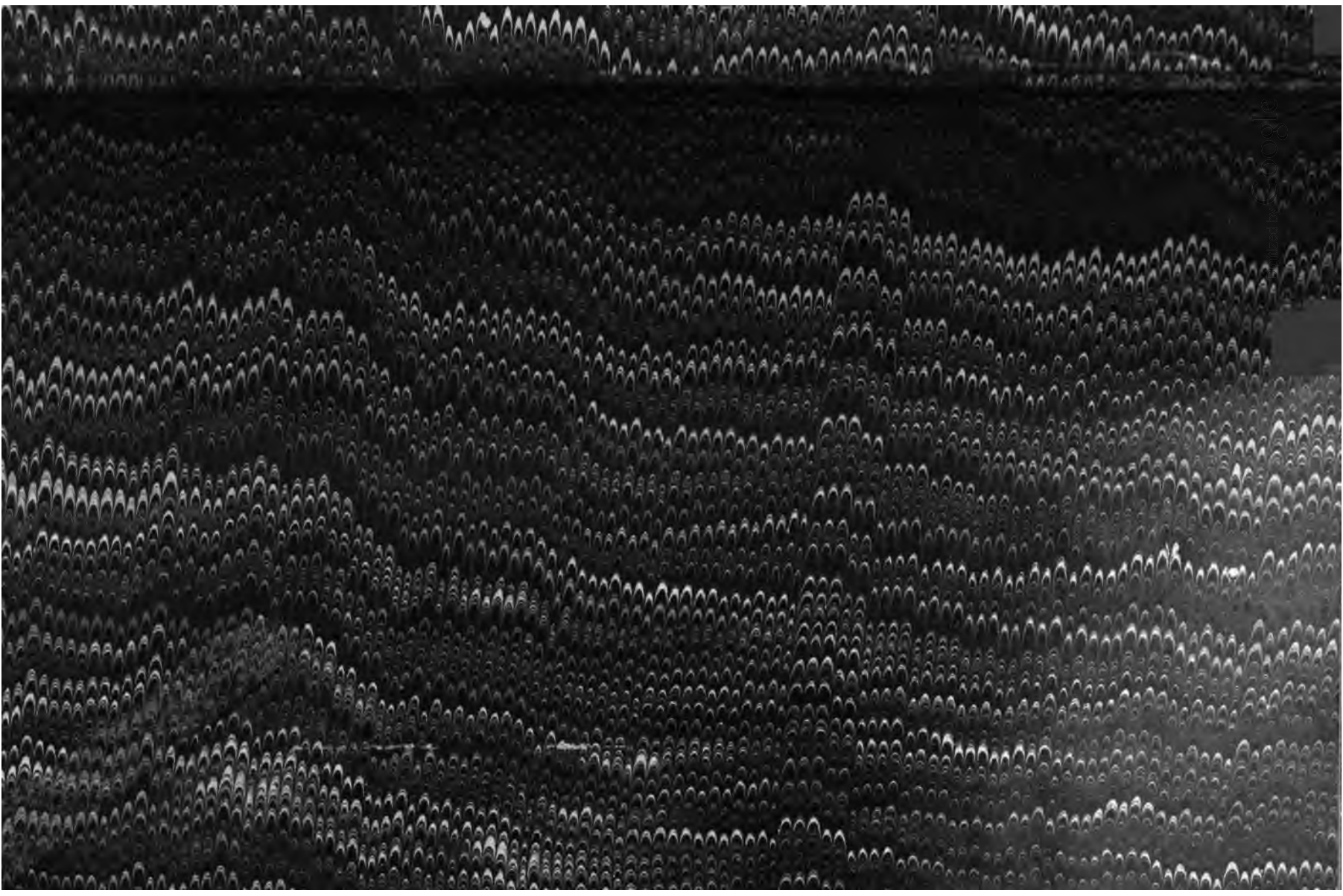

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